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NASA's CONTRIBUTIONS TO  
PATIENT MONITORING

Appendix Volume

by

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Prepared for

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Technology Utilization Division  
Washington, D.C. 20546

## PREFACE

This report documents part of a study being conducted by Abt Associates Inc. for the Technology Utilization Division of NASA to analyze NASA's contributions to the state-of-the-art of various fields of technology as it relates both to aerospace and non-aerospace communities.

The report appears in two separate volumes. The first (and main) volume contains an introduction to the field of patient monitoring, a discussion of NASA contributions to cardiovascular monitoring, and an analysis of two NASA innovations in intracardiac blood pressure monitoring. There is also a brief discussion of NASA technology transfers that have occurred. The second volume of the report is an appendix volume with additional information on health care problems, markets for patient monitoring equipment, NASA contributions to all phases of patient monitoring, reference material for the NASA innovations described, and information about the transfer of these innovations to non-aerospace problems. There is some duplication of information in the two volumes. The first and fourth sections of the main volume are condensations of Chapters 1, 2, and 5 of the Appendix Volume. The second section in the main volume on cardiovascular monitoring is included in Chapter 3 of the Appendix Volume because, in Chapter 3, references are made to additional information provided in the Appendix Volume.

This study is under the direction of Warren D. Siemens, Manager, Technology Management Group. Principal Advisors to the study are Robert H. Rea, Vice President and Dr. Richard N. Foster, Director of the Technology Management Group. Donald M. Murray had primary responsibilities for the research and writing of this report on NASA's contributions to the field of patient monitoring. Statistics on the biomedical electronics industry were compiled by Robert J. Cooper.

We appreciate the cooperation and assistance provided by numerous individuals at NASA headquarters and the various NASA Field Centers. The Project for the Analysis of Technology Transfer at Denver Research Institute graciously provided us access to their transfer case files on selected items of technology. The Biomedical Applications Teams at Research Triangle Institute, Midwest Research Institute and Southwest Research Institute also provided information on specific transfer cases resulting from their activities.

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## 1.0 HEALTH CARE: A CRITICAL LOOK AT MEDICAL, TECHNICAL AND ECONOMIC PROBLEMS

This chapter presents a more detailed discussion of the complex problem of health care. There are many interacting factors that are social, political, economic, medical and technical in nature. Chapter 1 is primarily concerned with only the latter three (economic, medical and technical) as they relate to the problems of health care and the solutions urgently called for.

### 1.1 Manifestation of the Problems

There have been great strides in health progress over the past 50 years. Medical science has advanced to the point where it is possible to alter the course of disease, to alleviate suffering, to terminate severe illness, to prevent crippling, and to postpone untimely death. Wonder drugs such as penicillin now provide immediate cures for diseases such as lobar pneumonia, which 25 years ago claimed 25% of its victims. Major fatal diseases such as whooping cough, diphtheria, polio and typhoid fever have been effectively eliminated.\* However, progress has been leveling off over the past two decades. The primary indices of health, life expectancy and infant mortality have not changed significantly in the United States. Figure 1-1 delineates life expectancy figures for males and females in the U.S. during the period 1900 - 1964. From 1959 to 1966, life expectancy of males in the U.S. dropped from thirteenth to twenty-second place among the nations of the world; similarly, and life expectancy of females dropped from seventh to tenth place internationally.

The same lag in improvement is demonstrated by the infant mortality rate. Figure 1-2 displays this sensitive index for the period 1913 to 1964. There has been a sharp decline in infant death rates during this period, however, the rate is steadily leveling off. Although this fact

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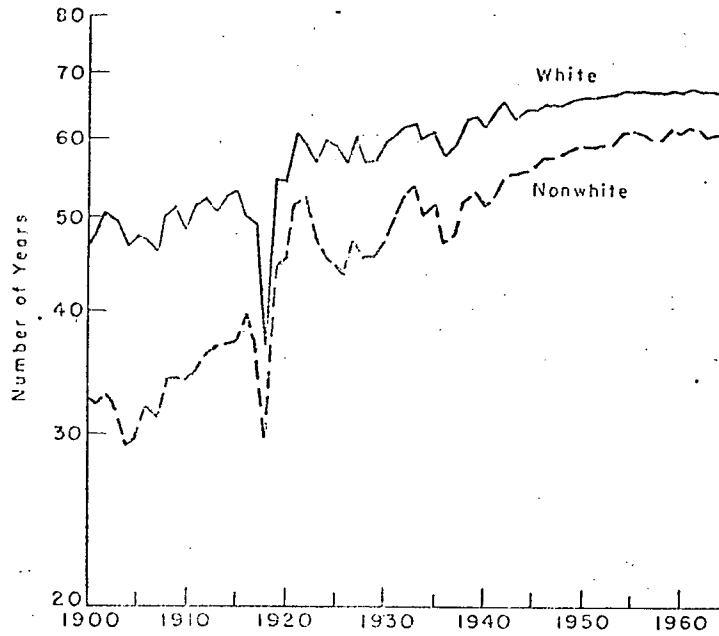
\* D. D. Rutstein, The Coming Revolution in Medicine, M.I.T. Press, Cambridge, Mass., 1967.

in itself might not be significant, it assumes a great deal of importance given the fact that the U.S. has fallen from eleventh to eighteenth in infant mortality ranging among the countries of the world.

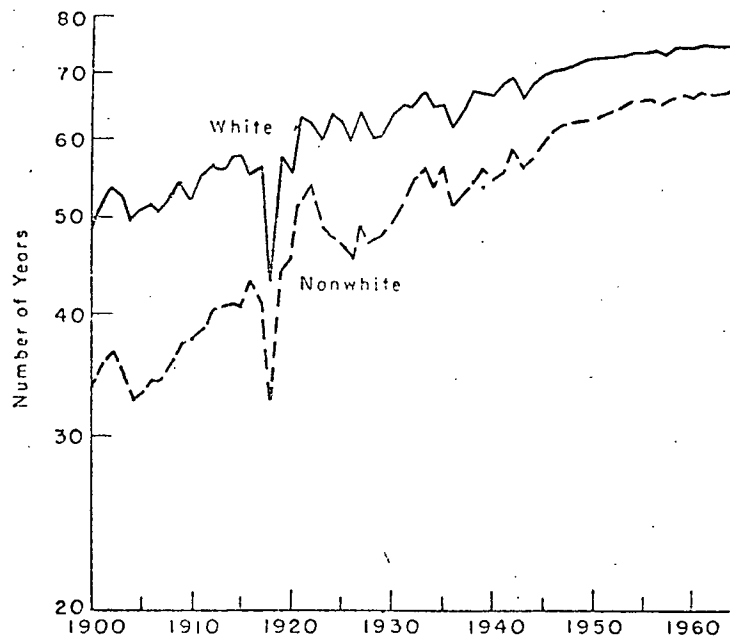
The apparent lack of improvement in health care does not appear to be not related to insufficient funding. In fact, expenditures in health care have been increasing at unprecedented rates. As Figure 1-3 indicates, total spending for health care services has increased almost 2 1/2 fold during this decade alone.



Figure 1-1



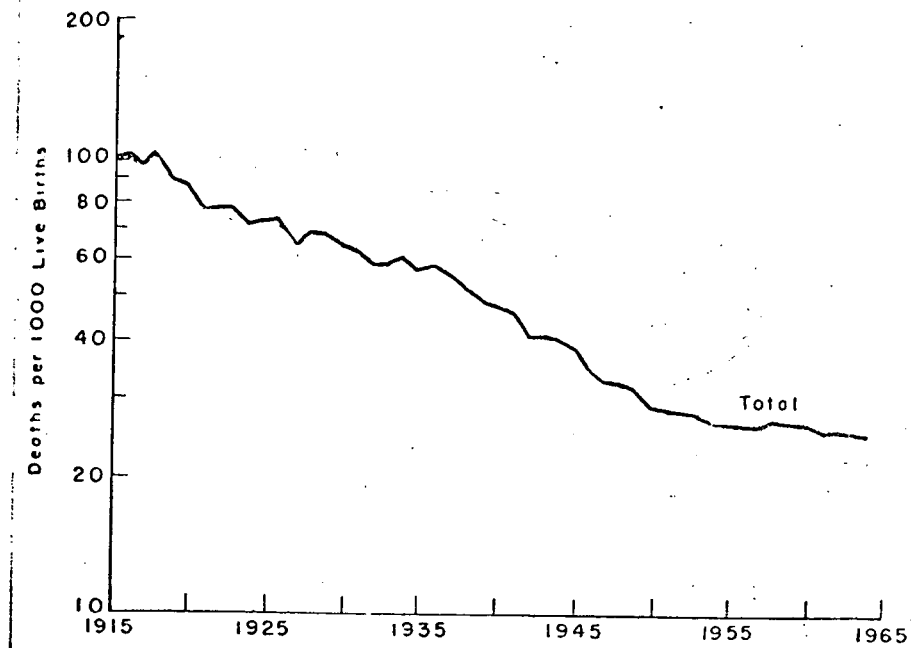
Expectation of life at birth in the United States, 1900-1964: Males.  
(Data include all states after 1933.)



Expectation of life at birth in the United States, 1900-1964: Females.  
(Data include all states after 1933.)

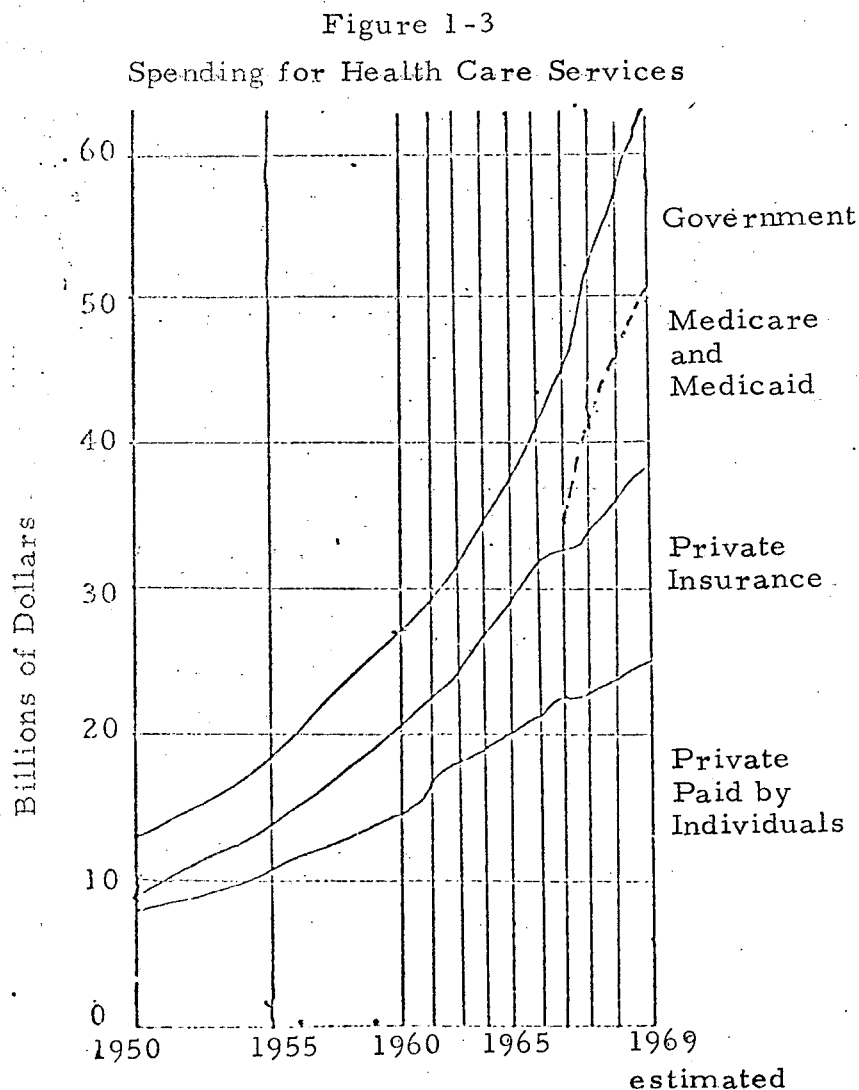
Source: D. D. Rutstein (see Figure 1-2).

Figure 1-2



Infant mortality rates in the United States,  
1915-1964.  
(Data include all states after 1933.)

Source: D. D. Rutstein, *The Coming Revolution in Medicine*, The M.I.T. Press, Cambridge, Mass., 1967.



Source: Fortune Magazine, January 1970.

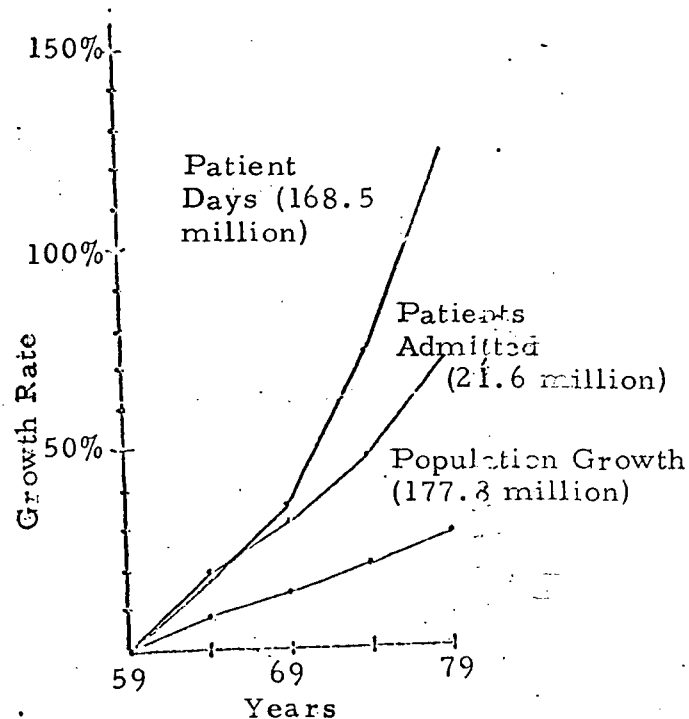
While total health care spending in the '60's increased at a 10% annual rate, government spending increased by 16%. The increased government involvement was due to the comprehensive medical care programs implemented in 1966, which were designed to provide health care services for the aged and the economically deprived. With the introduction of this plan, government expenditures increased from a growth rate of 6.8% annually to 28.7%. In 1969, Medicare and Medicaid alone represented 40% of the budget with over 7,000 hospitals, 4,700 extended care facilities, 2,100 health agencies and 2,600 clinical laboratories participating in the program. Forecasts show that government spending should maintain a 15% annual growth rate in the '70's.

One of the main causes for such substantial increased spending has been the increase in hospitalization.

In 1959, 21.6 million patients spent an average of 7.8 days in a hospital for a total of 168.5 million patient days. In 1969, because more patients spent a longer period of time in the hospital, patient days reached 200 million. By 1979, patient days are expected to increase by 63% as thirty percent more patients spend an average of two days longer in the hospital. (See Figure 1-4).

Figure 1-4

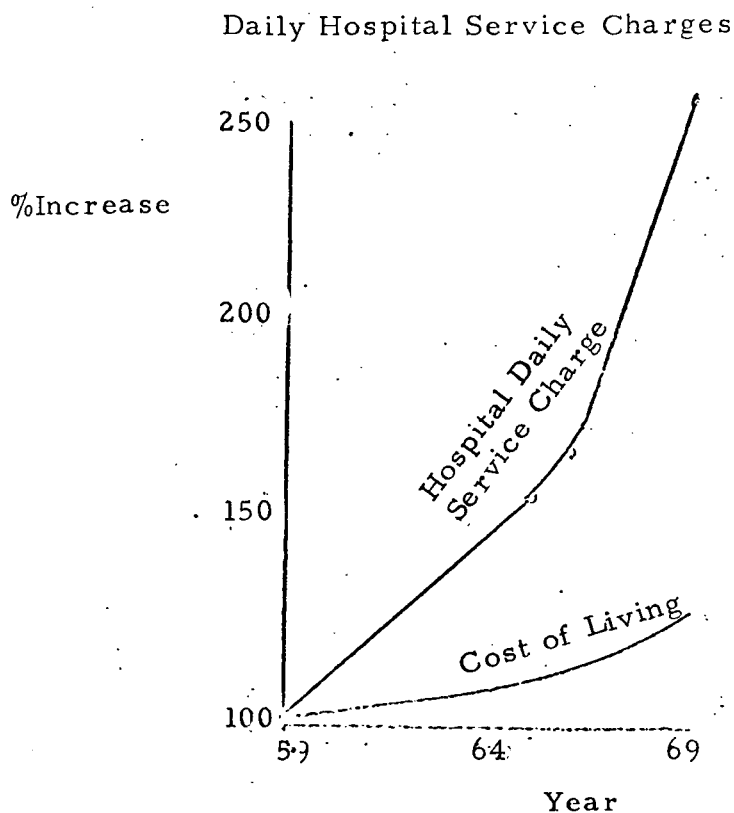
Non-Federal Short Term  
General Hospital Demand



Source: Predicast Report, Biomedical Electronics: Patient Care Systems, 1970.

With demand for hospital services increasing from 9.5% of the population in 1959 to 14.0% in 1969 to an estimated 16.3% by 1979, and with medical procedures becoming more extensive and more complex, a greater number of hospital personnel at a higher unit cost will be required to provide the patient with a better standard of health care. Figure 1-5 shows that while the cost of living index has increased by 25% between 1959 and 1969, daily hospital service charges increased by 160%. Hospital labor costs are partially responsible for this dramatic rise. Not only have labor costs increased from 57% of the total costs in 1947 to 66% in 1966, but the number of hospital personnel per 100 patients has increased from 208 in 1959 to 285 in 1969.

Figure 1-5



Source: Fortune Magazine, January 1970.

It is hoped that in the 70's increased expenditures on biomedical electronic equipment will provide for automation of the more routine hospital tasks; thereby reducing the demand for hospital personnel.

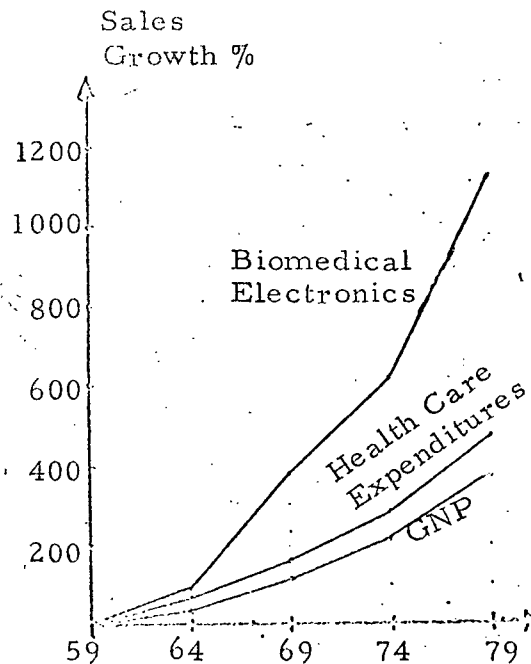
## 1.2 Biomedical Engineering Expenditures

There are numerous factors which must be considered for the solution of the nation's health care problems. It is generally agreed that a major requirement is an extensive overhaul of the entire health delivery system. In addition, the increased use and improvement of biomedical engineering equipment should prove to be an important vehicle for improved patient care. Instruments for the preventive, diagnostic and therapeutic treatment of disease can greatly enhance the quality of care delivered to patients.

Increased expenditures in biomedical engineering and biomedical research are expected to be able to provide the technology required for quality patient care. The National Institute of Health alone are spending \$50 to \$60 million a year on research and training in biomedical engineering; while the federal government, which spent \$2 billion in 1965 on biomedical research, is forecasted to spend \$16 billion annually by 1985. This will result in an increase in professional man power of 130% over the 1965 level of 64,000.

Biomedical electronics which accounted for .9% of the health care industrial sales in 1959 and 1.3% in 1969, should account for 1.9% of sales by 1979. This represents an annual growth rate of 13%, compared to 9.5% for the health care industry and 8% for the GNP. (See Figure 1.6).

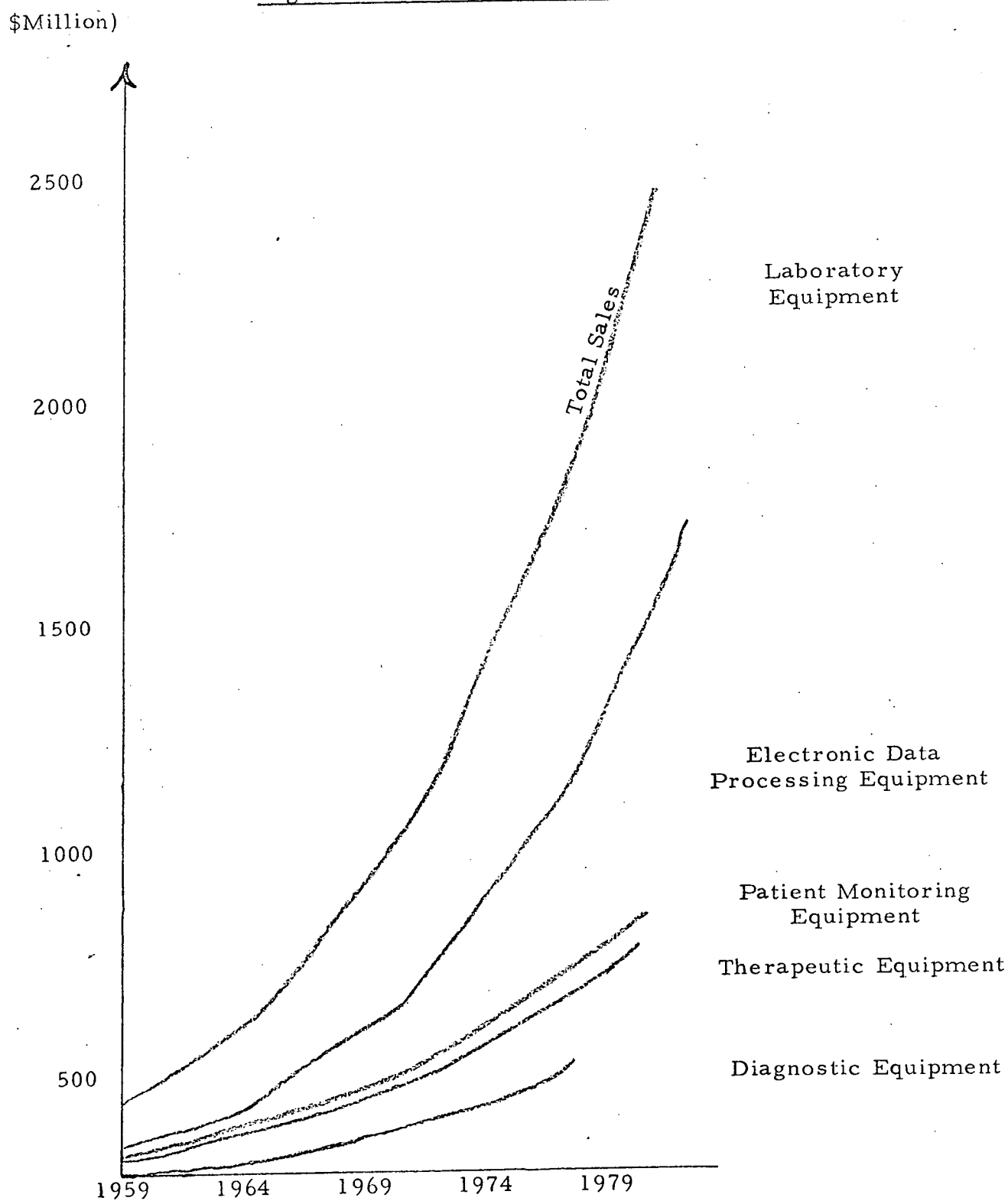
Figure 1-6



Source: Predicast Report, Biomedical Electronics: Patient Care Systems, 1970.

Biomedical electronics can be divided into five equipment categories: diagnostic, therapeutic, patient monitoring, electronic data processing, and laboratory equipment. Figure 1-7 shows a breakdown of the sales in these categories from 1969, projected through 1979. Electronic Data Processing and Patient Monitoring will continue to outperform the industrial average because these two categories offer the greatest potential for reducing labor costs and providing better health care.

Figure 1-7. Biomedical Electronic Equipment Sales



Source. Predicast Report, Biomedical Electronics/Patient Care Systems 1970, and Biomedical Electronics 1967.



Analytical laboratory equipment which offers more speed and better accuracy at a lower cost per test should also perform well. In Therapeutics, much of the growth will come from new and improved products as recent research efforts begin to pay off. In diagnostics, much of the growth in the 70's will come from the increased use of established equipment.

Design standards for patient monitoring equipment have become increasingly important because of the hazards involved in connecting a patient to a large bank of electronic equipment. An FDA survey indicated that between 1963 and 1969, there were 676 deaths and over 10,000 injuries due to improper use or faulty equipment. As little as 1/10000 of an amp traveling through the heart via a cardiac catheter can cause fibrillation and possible death. For reasons such as this, strict safety requirements have evolved.

Cardiovascular monitoring equipment has dominated and will continue to dominate, patient monitoring sales (Figure 1-9), due to the fact that continuous monitoring of patients with severe heart trouble can save many lives. For example, if ventricular fibrillation can be detected within 1 to 3 minutes after its onset, at least one-third of the patients afflicted can be saved. Such monitoring can only be accomplished by electronic equipment.

With approximately 1,500 firms active in the medical electronics industry, there is very little concentration of sales. A 1966 survey of 324 companies conducted at the University of Michigan showed that medical equipment sales in two thirds of the companies which responded totalled less than \$500,000; while only one quarter of the firms exceeded \$1,000,000 in sales. It would seem that for small companies in an industry characterized by low volume products and a geographically dispersed market, a large commitment to R&D and the need to provide extensive service is impractical.

### 1.3 Patient Monitoring Equipment Expenditures

Representing the second fastest growing segment of the biomedical electronics industry, patient monitoring accounted for 0.9% of the total sales in 1959 and 2.5% in 1969. Viewed as a life saving system which can monitor, collect and analyze mass quantities of data, patient monitoring is one of the most promising means of providing better care to the critically ill patient. The number of hospitals with intensive care units is rapidly growing (see Figure 1-8).

Figure 1-8

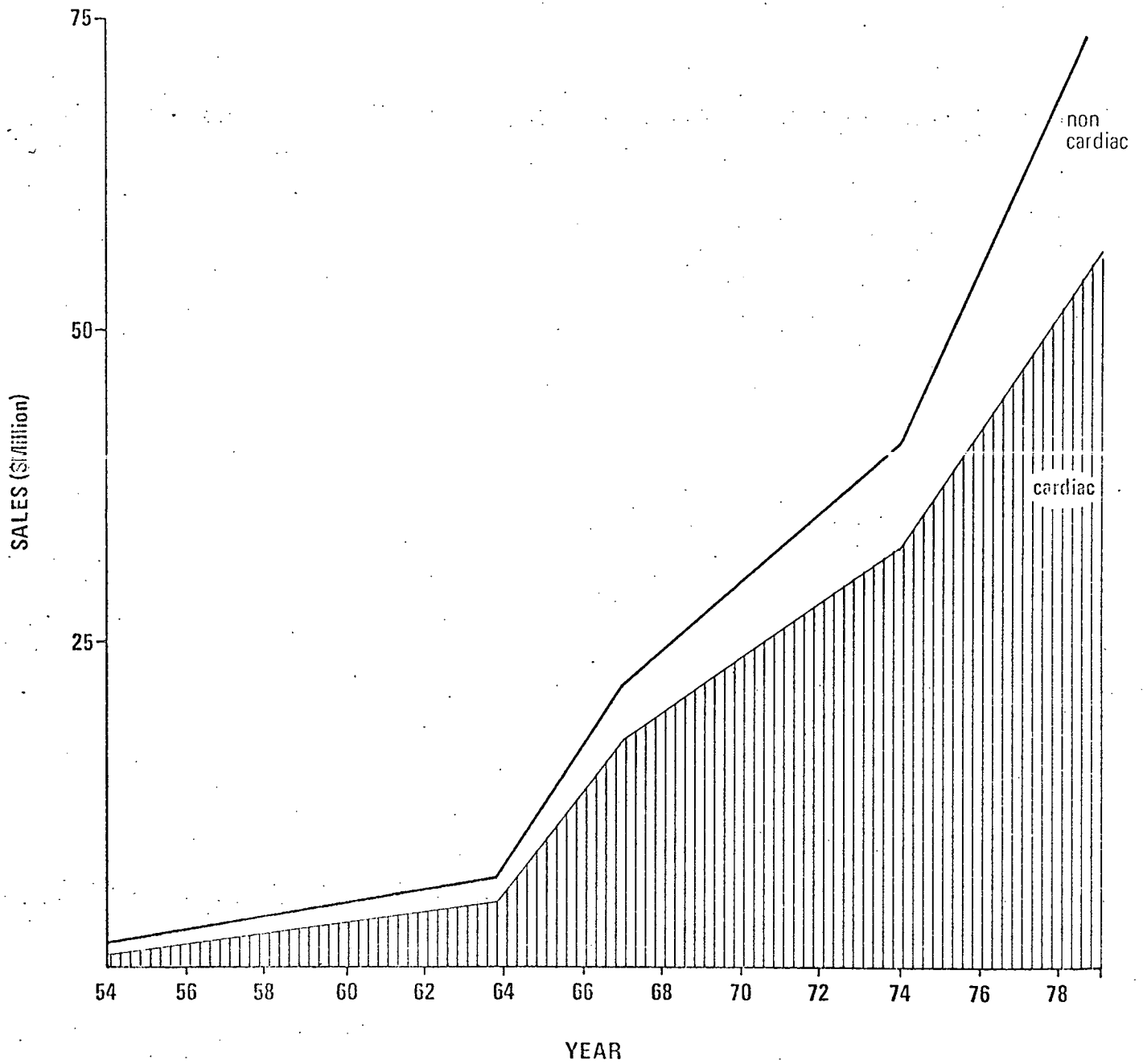
Year	Percent of Acute General Hospitals With Intensive Care Facilities
1960	10%
1966	32%
1970	40%
1971	56%

### 1.4 Future Prospects Due to NASA Influence

Bioinstrumentation and patient monitoring in particular, have proven to be important factors in the continuing improvement of health care. The design of more comprehensive and reliable equipment will be valuable to any patient undergoing hospital or clinical diagnosis and treatment. Patient monitoring is a rapidly growing field in which we can

Figure 1-9

PATIENT MONITORING SALES



Source: *Predicast Report, Biomedical Electronics: Patient Care Systems, 1970.*

look forward to extensive growth on the commercial market in the near future. NASA's development of innovative equipment holds great potential for significant impact, not only in the commercial world, but within the realm of improved patient care as well. This is particularly true because NASA requirements result in highly reliable, ultra-safe, and relatively new equipment. NASA contributions should assist in achieving development cost savings and, most important of all, the saving of lives.

Medical requirements are discussed in more detail in Chapters 2 and 3 will demonstrate the impact NASA has had.

## 2.0 HEALTH CARE MEDICAL REQUIREMENTS

Requirements for improved health care exist on several levels, from the overall need for a more efficient health care delivery system, to specific requirements such as transducers for transcutaneous blood pressure measurement. This chapter is concerned with the requirements on two levels: bioinstrumentation and patient monitoring. Through discussion of the types of requirements that exist, a stage will be set to evaluate the contributions to be discussed in the remaining chapters.

### 2.1 Requirements in Bioinstrumentation

Bioinstrumentation is instrumentation for the measurement, monitoring, analysis, and control of biological functions or quantities. The advances in bioinstrumentation are best made by the joint efforts of medical researchers and engineers interested in using their skills to increase the knowledge of biological functions. Efficient utilization of biomedical instrumentation techniques requires a thorough understanding of both the biological problem and the chemical, physical, technological and engineering science that can be applied to achieve its solution. The improvements made in bioinstrumentation have, to a great extent, been modifications or extensions of devices used in the physical sciences for the measurement of temperature, pressure, capacity, velocity, and electrical activity. However, the modifications are innovations in that they require a unique knowledge of the relation of biological functions to the physical sciences. The considerable diversity of medical instrumentation and its importance, both socially and commercially, have resulted in a valuable area of design for the bioengineer. The tasks are intellectually challenging because they often require sophisticated state-of-the-art capabilities.

Design criteria for biomedical instrumentation is more rigid than for other types of instrumentation. The dominance of metabolic processes by low frequency variations places restrictions on the frequency requirements of equipment. Transducer impedance must be compatible with the impedance of the bioelectric phenomena under measurement. Currents delivered to the human body in the event of equipment failure must be less than 1 milliamp

(or less than .1 milliamp directly to the heart).<sup>\*</sup> Implanted instruments must be small, inert, reliable, and long lived. All of these requirements place important restrictions on the design and construction of medical instruments.

Bioinstrumentation equipment includes many types of transducers, both passive and active. Passive transducers, previously mentioned above, are devices which are used to detect physiological quantities. Active transducers are instruments which deliver power to the body for the purpose of diagnosis and treatment. The most common type of active transducer is the X-ray used for diagnostic purposes. Radiation is also used as an active treatment for cancer.

Newer techniques involve the use of high frequency electrical currents passed through the body to detect impedance changes. In addition, active electrical stimulation of the fibrillating heart muscle can be used to restore the heart to its normal state.

The impedance changes during respiration can be utilized to determine respiratory rate, volume, and flow. The most important bioinstrumentation development would seem to be the use of ultrasonic doppler techniques to assess atherosclerotic disorders in arterial walls of superficial arteries. This technique will prove valuable in the early diagnosis of crippling and fatal cardiovascular diseases which cause more deaths than any other type of disease in the United States.

There is an urgent need for the continued development of advanced engineering applications to biological monitoring, analysis and treatment. Instrumentation is the tool of the physician and, through the development of increasingly sophisticated equipment, the physician will be capable of more reliable and preventive diagnosis and treatment.

## 2.2 Requirements in Patient Monitoring

Patient monitoring is one of the major applications of bioinstrumentation equipment which involves the continuous (or frequent relative to the period of time required for significant change) monitoring of human physiolo-

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<sup>\*</sup>U.S. Department of Health, Education and Welfare, Public Health Service. Electronics for Hospital Patient Care. Hospital and Medical Facilities series, the Hill Burton Program, Silver Spring, Maryland, November 1968 and July 1969.

gical functions. Monitoring is used in intensive care units, during surgery, in post-operative recovery rooms and even during clinical screening.

Although monitoring equipment will never replace the physician's diagnostic capabilities, it does assist him in making a rapid diagnosis by alerting him to a critical situation. Patient monitoring equipment can quickly provide reliable patient information that normally would be difficult to obtain. The value of such information cannot be overstated because the availability of the data is a direct determinant of the survival of the most critically ill.

General objectives of patient monitoring systems are:

- (1) The system should be designed as a method of obtaining more reliable information to assist medical personnel. The system should be capable of monitoring some of the more repetitive tasks which are tedious to medical personnel and lead to a reduced level of attention.
- (2) The system should supply more than one level of monitoring. A standard level of basic monitoring for the low risk patient will suffice, but advanced monitoring must be available for the critically ill patient.
- (3) The attachment of transducers for routine monitoring must be easy, fast, and reasonably comfortable for the patient.
- (4) Finally, the patient's data should be managed with the aid of a digital computer.

The basic function of monitoring is the accurate detection of information which is of direct biological significance. The transducers used for detection have unfortunately fallen behind the development of other instrumentation. The ability to process signals has developed far beyond the ability to sense them. This lag can be explained by the fact that the high-speed digital computer has been a source of considerable practical and intellectual interest in many phases of science and industry; however, the development of new transducer designs is rather unique in requirement and is a rather difficult process to accomplish. Fortunately, as Chapter 3 indicates, NASA has been involved in extensive transducer development which has significantly advanced the state-of-the-art, and decreased the lag described above.

Specific requirements for patient monitoring equipment include the need to determine cardiac output, atherosclerotic disorders, precise intracardiac blood pressure, the effect of exercise on the cardio-pulmonary system, and respiratory gas analysis. Some of these requirements result in the need for extensive improvements in existing equipment. Other requirements imply that new and innovative equipment must be developed. These improvements and developments have far reaching effects on the quality of health care delivered to all patients.

### 2.3 Scope and Impact of NASA Solutions

NASA has made many advances in equipment which are applicable to patient monitoring techniques. There have been contributions to many phases of cardiovascular monitoring: a few examples being; EKG electrodes, cardiac output, cardiometers, cardiac blood pressure measurement, and blood flow measurement. Other aerospace devices have been successfully used for the monitoring of respiratory functions, electroencephalograms, chemical analysis, vision testing, bone density measurement, radiation detection and intragastric functions. The NASA achievements relate very closely to the requirements of patient monitoring systems. The remaining chapters of the report present further description and analysis of patient monitoring equipment.



### 3.0 NASA ACHIEVEMENTS IN PATIENT MONITORING

This chapter presents NASA contributions to the field of patient monitoring; focusing most heavily on relatively new developments. However, also included are earlier achievements which were extremely valuable and which still hold the forefront in technology. This section is not meant to include all NASA contributions, but it does contain a selected sample which is quite representative.

The minimum criteria for the selection of items to be mentioned is that they advance the state-of-the-art at the time of their introduction. However, almost all of the items have had much greater impact through direct transfers of technology to non-aerospace use. It is impossible to keep track of all the transfers that occur because so many are on a local and informal level. However, it is very impressive to learn of the cooperation that goes on constantly between NASA personnel and the outside medical profession. Physicians and technicians have come to rely on assistance from NASA scientists in developing more sophisticated apparatus and techniques. Occurrences such as the use of a centrifuge to save a patient's life, the design of a respiration monitor for hospital use, fabrication of an EEG cap with electrodes for use on mental patients, the use of an anti-g suit to save a hemorrhaging patient's life, and extensive advice on electrode design are a few examples of the spontaneous assistance NASA has given.

Further information may be found in Appendix A for each of the instruments or techniques discussed. Each item is referenced by a superscript number. The information in the appendix consists of: Inventor(s), NASA center at which work was done, documents and papers available, transfer information on known users, and manufacturers of the equipment. The list of transfers may not necessarily be complete because it is not the intention of this report to seek out new transfers, but to summarize those which have already been reported.

#### 3.1 Patient Monitoring

The term patient monitoring as it is used in this study is meant to include not only the monitoring of patients in intensive care units or in

surgery, but also patients undergoing routine tests and clinical observation for the purpose of screening and diagnosis. Monitoring of out-patients at a screening facility to determine the presence of disease is becoming an important technique for early diagnosis. The patient may be asked to exercise while being monitored to determine the response of his cardio-pulmonary system. Although this approach is becoming increasingly popular, a vast majority of monitoring equipment is still being used in intensive or coronary care units.

The critically ill patient has a much better chance of survival in an environment where there is continuous care and surveillance. The more seriously ill a patient is, the less deterioration of condition can be tolerated and the sooner the corrective action must be taken. Consequently, continuous monitoring is of vital importance; an impossible task with the use of only nursing staff. Equipment which can automatically monitor a patient and alert a nurse or physician in case of emergency is urgently needed. Although the number of hospitals which monitor patients is rapidly growing, there is still a demand for improved and more comprehensive equipment.

NASA has been working on improvements over existing apparatus and has also been funding work on research into new devices that measure physiological functions never before monitored. Both types of contributions have shown great rewards for non-aerospace uses.

### 3.2 Specific NASA Contributions to Patient Monitoring

The discussion below is broken into eight sections according to types of physiological functions, e.g., cardiovascular. Some of the sections have been subdivided further into actual physical parameters that are measured. The parameters discussed are those for which NASA has developed specific monitoring equipment or techniques.

Section 3.3 will discuss NASA contributions to patient monitoring which are not unique to any single function or parameter. An example would be the automated patient monitoring system which can monitor cardiovascular, respiratory, or other functions of the body, and transmit relevant information to medical personnel.

### 3.2.1 Cardiovascular Monitoring

The condition of the cardiovascular system is vitally important. If the flow of blood is stopped, the body will rapidly deteriorate and irreparable brain damage will occur within only four minutes. For these reasons it is extremely important to closely observe a patient whose circulatory system is damaged or weakened. Observation of pulse rate and blood pressure every few minutes is insufficient for a patient in critical condition; these and other parameters must be monitored continuously. The most feasible solution is the use of electronic equipment which can immediately alert a nurse or physician in case of a significant change in heart function. Rapid detection of coronary malfunctions can be the key to saving the lives of many cardiac patients.

Electronic equipment is used to monitor the heart in non-critical situations as well. The electrocardiogram has been used for years to assist physicians in diagnosing heart damage. This type of testing is sometimes called diagnostic monitoring and is used to detect heart damage or irregularities before they become a serious hazard to the patient's health.

In addition to pulse rate and blood pressure, important parameters for cardiovascular monitoring are: electrical signals generated by the heart muscles, cardiac output, intracardiac blood pressure, heart sounds, blood flow, and oxygen saturation. New and improved monitoring equipment for detection of these heart functions is constantly being developed.

#### Electrocardiography (EKG)

One of the most important and well-established methods of monitoring the heart is the technique of recording the heart's electrical activity. The electrocardiogram, as the record is called, can be used to

detect heart damage or defects. To perform this task it is necessary to attach electrodes to the chest of the patient. Attaching the electrodes can be time consuming and irritating to the patient because it may involve shaving, cleaning, and abrading the skin to produce good contact, applying irritating electrode jellies and finally gluing on the electrode. Metal electrodes can irritate the skin because of their rigidity, and if they are thick enough the patient cannot comfortably lie on them. Most types of electrodes rarely remain securely fastened for more than a day and a half; if the patient does not remain stationary this time may be further reduced.

Because of the NASA requirement of monitoring the astronaut's EKG waveform, a large variety of electrodes and pastes of advanced quality have been designed. Many types of electrodes were developed at the Manned Spacecraft Center<sup>1</sup> for the purpose of long term monitoring without irritation or loss of contact. One type of electrode has remained in use for a period of fourteen days during which the subject participated in normal activity. Another electrode has been designed which requires only degreasing of the skin -- an inexpensive and disposable model which saves the time normally spent in cleaning the electrodes for future use.

The well-known spray-on electrodes<sup>2</sup> were developed as a result of a requirement at the NASA Flight Research Center. In order to perform routine monitoring of test pilots, it was necessary to instrument and check out a pilot in less than three minutes. The outcome was a product which could be used to apply a single electrode in 20 seconds. This has been useful for two separate non-NASA applications. First, the spray-on electrodes are valuable for use in EKG clinical screening because they can be applied quickly and removed easily without skin irritation. The electrodes maintain excellent contact for several hours even under active conditions, and can be used by physicians to obtain EKG's from a patient undergoing exercise. The technique of monitoring a patient's EKG during exercise may prove to be very important in detecting heart defects before they become serious.

Secondly, the spray-on electrodes have proved essential for ambulance EKG transmission systems because they may be applied rapidly

and reliably even under emergency conditions. The ability of a physician to examine a patient's EKG immediately after a heart attack is extremely important for proper diagnosis and treatment. The transmission system will be discussed in more detail further on in this section.

More recently, flexible electrodes<sup>3</sup> have been developed for extended space mission requirements during which a soft, body conforming, flexible electrode would be valuable. The electrodes consist of silicone rubber loaded with silver-plated particles, which can be molded or cut to fit comfortably over irregular body contours and move with the skin causing far less irritation than normal electrodes. Because of the comfort of the electrodes, they have excellent possibilities for long-term patient monitoring, especially for infants on whom currently available electrodes are quite large and uncomfortable. In addition to the electrodes, flexible wires have been used as connectors which are comfortable and less likely to break from body movement.

As indicated above, multitest screening facilities and emergency situations have created the need for electrodes which can be applied rapidly. In addition to the spray-on electrode, NASA is developing a harness containing six electrodes<sup>4</sup>. The harness can be applied quickly and may prove to be even more efficient than the spray-on electrodes, thus saving much time in clinical testing facilities.

NASA has funded work on a contourograph display system<sup>5</sup> for presentation of EKG data. Contourography is a technique for presenting repetitive analog signals in a highly informative manner. Using this technique, each cycle of a semi-periodic signal is displayed on one of a series of separate horizontal baselines. A major change in the signal stands out from the regular pattern. The EKG may be displayed using the contourography format with the result that each heart beat appears as a series of waveforms. By observing the contourograph, a physician can quickly detect heart irregularities or arrhythmias. The contourograph developed previously by Webb did not display the EKG waveform in its accepted time sequence and the contourogram was generated on a photographic film strip, resulting in a delay for the physician.\* NASA's device displays the

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\* Golden, D. P., G. Maudlin, and R. A. Wolthiers, "Real Time Cardiography -- An Improved Electrocardiographic Display", IEEE Transactions on Biomedical Engineering, October 1970.

waveform in the correct sequence by using an improved triggering scheme. The waveform is shown on a variable persistence CRT, thus supplying the physician with a real time display of EKG signals.

More than 60% of the deaths from heart attacks occur within an hour after the onset of the attack. Normally the time a patient spends in an ambulance cannot be used for diagnosis or treatment; however, with a system developed as a result of NASA work, it is possible to transmit a patient's EKG from the ambulance to the hospital.<sup>6</sup> This would assist a physician at the hospital in diagnosing a patient before the ambulance has arrived and might even allow the doctor to instruct the ambulance attendant to perform critical treatment. NASA was the pioneer in developing the ambulance EKG transmission system. Use of the spray-on electrodes allows the patient to be connected to the monitor very quickly.

#### Cardiac Output

NASA has funded work on a four electrode impedance plethysmographic system<sup>7</sup> for monitoring ventricular stroke volume or cardiac output. This device has tremendous potential for clinical use and has already been used to monitor heart transplant patients during the post-operative follow-up period. The system allows a physician to closely monitor the volume of blood passing through the heart without the need for surgically implanted electrodes or transducers. The NASA work resulted in the following improvements:

- (1) Only a single channel recording is needed instead of two,
- (2) The errors introduced in estimating ventricular ejection time from obscured heart sounds are reduced by the new method of ventricular ejection time detection,
- (3) Further reduction in error by the elimination of the graphical slope extrapolation method and use of the peak magnitude of the rate of change of impedance, and
- (4) The development of more comfortable electrodes.

The importance of this device is that the failing transplanted heart can be detected at an early stage by monitoring the stroke volume analog.

Incipient rejection is indicated by a progressive reduction in stroke volume. Thus, corrective action may be taken before it is too late.

At the Ames Research Center an implantable miniature ultrasonic sonomicrometer<sup>8</sup> has been developed and used to measure the dimensions of the left ventricle and the changes in dimension during a heart beat. The device uses the echoes of high frequency sound waves bounced off the front and rear walls of the heart to electronically determine the heart dimensions. The implantable device has proved feasible and work on a transcutaneous sonocardiometer is under initial development. The sonocardiometer would be strapped to an astronaut to monitor his cardiac functions and to assess the affects of weightlessness and acceleration. For a patient with heart trouble, this device will be able to provide the means for determining the volume of blood ejected from the heart at each beat, the presence of backward flow indicating valve leakage, and the heart size. Present techniques require catheterization of the heart for which the patient must remain in the hospital.

#### Phonocardiography

Phonocardiography is the process of obtaining and recording the sounds produced by the heart. This technique provides information different from EKG tests and presents the physician with additional data in the diagnosis of cardiac defects. A microphone<sup>9</sup> has been developed for the detection of the heart sounds. This microphone has a better frequency response as a result of shifting the resonance peak outside the frequency band of interest (20-2,000 Hz). It is small in size and readily adaptable to mass production techniques.

In addition, NASA is developing a heart sound preprocessor<sup>10</sup> which employs methods that give the signal the following advantages:

- (1) It is easier to program for computer analysis and requires far less computer storage,
- (2) It can be transmitted by standard FM techniques used for other medical signals, and
- (3) It is easier to relate to the audible sounds a physician is accustomed to hearing.

The result will be a preprocessor which will enhance the physician's ability to use phonocardiography in detecting heart defects.

### Vibrocardiography

Vibrocardiography<sup>11</sup> is the detection of the acceleration of the chest wall resulting from the movement of the heart during the cardiac cycle. It has been shown that the accelerations are strongly related to the stages of contraction, ejection, systole and diastole and that vibrocardiography may produce a record of these as accurately as the method of cardiac catheterization. In order to detect the extremely small accelerations involved, it is necessary to use a very sensitive transducer. NASA has funded the development of a transducer which has excellent frequency response (1.6 to 3,000 Hz,  $\pm 3$ db), and a dynamic range of 90 db.\* This instrument will provide the physician with highly accurate and detailed vibrocardiogram recordings.

### Cardiotachometer

A cardiotachometer is a device which monitors and displays heart rate. It is used for a patient in an intensive care unit or during surgery and might even be used to monitor a subject undergoing cardiovascular stress analysis. A cardiotachometer with linear beat-to-beat frequency response<sup>12</sup> has been designed by NASA. It has a linear response over the range of 30 to 270 beats per minute and an accuracy of  $\pm 1$  beat per minute. It is capable of continuously displaying the heart rate with a beat-to-beat indication of rate change rather than an averaged rate change. Previous devices required 15 to 20 seconds to register a change from 60 to 120 beats per minute. In critical situations, this delay may not be tolerable.

### Cardiac R-Wave Detection

In order to coordinate a heart assist device with the action of a failing heart, it is necessary to obtain a reliable electrical signal that

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\* Jones, William J. and Wyatt C. Simpson, NASA Contributions to Cardiovascular Monitoring. Prepared under contract for NASA by Westinghouse Electric Corporation, U.S. Government Printing Office, Washington, D.C., 1966.



occurs naturally during the heart's systolic contraction. The R-wave portion of the pronounced QRS complex that occurs at the beginning of the heart's pumping cycle can be used to control a heart-assist pump. Previous R-wave detectors have not been totally satisfactory because they occasionally miss pulses or falsely trigger with resulting erratic pumping. A detector<sup>13</sup> developed by NASA has been found to be extremely reliable and accurate. It has been used in conjunction with a NASA artificial heart controller.

### Cardiac Blood Pressure Measurement

In intensive care units or during heart surgery it is frequently necessary to monitor the pressure within a patient's heart. A commonly accepted procedure is to insert a catheter through a vein and into the heart. The catheter may either be filled with a fluid and have a transducer at the end (external to the patient's body) to sense the pressure changes transmitted by the fluid, or the catheter may have a transducer at the tip which is inserted into the heart. Catheters with tip transducers are potentially superior because they sense the pressure directly. However, the tip transducers available are relatively large in size, increasing the chances of damage or obstruction to the vein. NASA has been responsible for the development of two different types of transducers<sup>14, 15</sup> for the use on tips of catheters. They are much smaller in size than any presently manufactured (.04 and .02 inches instead of the commercially available .08 inches). In addition, they have better frequency responses which are valuable in obtaining accurate pulse wave forms and possess lower power requirements. The result is that the transducers are highly safe, reliable, and capable of accurately detecting the pulse wave form.

### Indirect Blood Pressure Measurement

Blood pressure measurement is probably the diagnostic technique most frequently used by physicians today. The standard instrument is called a sphygmomanometer, and must be used by an experienced nurse or doctor. NASA has been extensively involved in blood pressure monitoring. One of the earliest devices was an automatic sphygmomanometer,<sup>16</sup> used on the Mercury and Gemini flights. It consisted of an

automatically inflating occluding cuff with gas pressure source, gas pressure regulator and valve, transducer for cuff pressure, and a microphone to detect the Korotkoff sounds. The device has been used clinically and was found to be more accurate than the standard manual clinical method.\*

Another technique employs a transducer as a direct force balance probe<sup>17</sup> to detect the force required to restrain arterial deflection. Although the technique has not been perfected, its feasibility has been demonstrated.

A second type of transducer<sup>18</sup> has been developed for placement on the ear. The device uses cyclic-occlusion of the ear pinna combined with measurement of variations in the opacity of the ear capillary bed to detect blood pressure. The system has been tested and found to be more accurate than the standard method of pressure measurement.

A technique for rapid venous pressure measurement is being investigated.<sup>19</sup> Normally quantitative venous pressure measurement requires direct entry into a vein. This new method requires only that a patient exhale through a constricted orifice which causes the pressure to rise in his lungs and the surrounding area including the heart. The pressure measured orally is equal to the venous pressure at heart level. If the oral pressure is increased enough the blood flow toward the heart in a vein in the arm will cease when the arm is at heart level and the oral pressure is equal to or greater than the venous pressure. A transcutaneous doppler blood flow sensor is used to detect the flow cessation. This method may be of significant value to the clinician in providing rapid non-invasive venous pressure measurement.

### Blood Flow

NASA has been funding the development of non-invasive ultrasonic techniques for study of peripheral arterial and venous blood flow. The instruments inject high frequency sound into an artery or vein and detect the phase shift that occurs in the sound which is reflected off of particles in the blood in order to determine the blood's velocity. Electromagnetic flowmeters have been developed by other researchers but they produce

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\*Ibid

only an averaged flow velocity. Prior to NASA research the only ultrasonic flowmeters available gave only qualitative information on flow velocity.

NASA funding has resulted in two innovations. The first was the development of a continuous wave doppler flowmeter capable of sensing direction of flow<sup>20</sup>. The blood reverses direction of flow in the arteries even in normal subjects. Detection of the reversal is advantageous in diagnosing a number of vascular diseases such as arteriovenous fistula, aortic regurgitation, or arteriosclerosis obliterans. Although other directional flowmeters are now available, the first clinically useable one was developed by a NASA researcher.

The second innovation has been the development of a pulsed doppler ultrasonic flowmeter.<sup>21</sup> This device cannot only detect the direction of flow, but is also capable of determining the cross sectional flow profile in an artery or vein as well as the internal diameter of the artery or vein. Again the NASA researcher developed the first clinically useable instrument in this country, if not the entire world. Although refinements are needed, the techniques have demonstrated their feasibility and value. The pulsed doppler is capable of producing considerably more information on the condition of the arteries or veins by indicating the location and nature of turbulent blood flow.

The goal of physicians is to obtain a device that can be used to screen patients for the early detection of circulatory diseases. This technique would be extremely valuable in treating a patient before he developed a serious incurable disease. One physician is already using the NASA device to detect (in addition to the diseases already mentioned): thrombophlebitis, occlusion of the internal carotid artery, thoracic outlet syndrome, accurate venous or low blood pressures, condition of arterial grafts, and the condition of a vein or artery during and after catheterization.

In summary, the NASA developed ultrasonic blood flowmeters show great promise for the future of research and diagnosis of peripheral vascular diseases.

### Blood Oxygen Saturation

It is frequently necessary to determine the oxygen saturation in a patient's blood because it is an important indicator of his condition. NASA has sponsored the development of an oximeter<sup>22</sup> which is used on the ear to detect the oxygen content in the blood. The saturation is measured by detecting the percentage of oxygenated hemoglobin in the blood with a photoelectric photometer. Oxygenated and reduced hemoglobin absorb different amounts of light of wavelength 640 millimicrons, but they absorb the same amount of light of wavelength 800 millimicrons. The device therefore uses the difference between the absorption levels to determine the oxygen saturation.

This instrument could be used to monitor a patient during surgery or in an intensive care unit. Continuous measurement could prove invaluable to monitoring a patient in critical condition.

### Cardiovascular Stress Analysis

This is a rapidly growing area of interest among physicians who feel it is important to observe the effect that controlled exercise or stress has upon the cardiovascular system. Stress can reveal a great deal of information about a patient's condition that normal testing cannot show. In addition to the monitoring techniques already discussed, NASA has developed equipment which can be used to measure a controlled amount of stress on a patient. A bicycle-like device called an ergometer has been devised and calibrated<sup>23</sup> in order to monitor the amount of work a patient is performing. In addition, the calibrator makes accurate calibration of any type of ergometer possible so that work rate can be determined and recorded. Therefore the work rate may be duplicated and the effect of exercise may be determined on different ergometers at various locations and under different conditions. Initially developed for studying the effects of weightlessness on astronauts, the ergometer and calibrator show promise as valuable tools for future research and diagnosis of cardiopulmonary diseases.

Another instrument called the lower body negative pressure device<sup>24</sup> was originally designed to test the effect of a weightless condition on the cardiovascular system of an astronaut in space. By subjecting the astronaut's

legs and lower body to a partial vacuum, the effect of pooling of the blood in the legs that occurs under gravity is simulated. Regular use by the astronauts may help keep the leg muscles in tone and save them from blood pooling and the resulting fainting spells when they return to earth after a long mission. This device could also be used on a subject to induce a controlled stress, enabling a physician to assess the state of his cardiovascular system. Monitoring a patient's reaction under stress will give early indications of defects that normal testing under rest conditions cannot.

In summary, NASA has been responsible for the development of equipment to monitor a large number of cardiovascular parameters: electrocardiographic signals, ventricular stroke volume, heart size, phonocardiographic and vibrocardiographic signals, heart rate, cardiac blood pressure, arterial blood pressure, venous blood pressure, blood flow velocity and volume in arteries and veins, diameter of arteries and veins, and oxygen saturation. Several devices such as the spray-on electrodes, ambulance EKG transmitter, impedance plethysmograph and the R-wave detector have already been used and found to be extremely valuable. Fortunately, NASA is continuing its pioneering work in cardiovascular monitoring and we can look forward to such things as, improved cardiac catheters and the use of ultrasonics in the detection of cardiovascular disease.

### 3.2.2 Respiratory Monitoring

Respiratory monitoring involves the detection and analysis of expired gases, their quantities and rates, and the respiratory rate. Such measurements are valuable in the assessment of respiratory diseases and cardiopulmonary relationships. Continuous monitoring of a patient with an acute pulmonary disease would give the physician a means by which he could observe the patient's progress in recovery or detect an emergency condition requiring immediate treatment. Respiratory monitoring can also be valuable for screening patients with suspected pulmonary disorders.

## Respiratory Gas Analysis

Continuous analysis of the alveolar gases is one of the most meaningful measurements available for respiratory monitoring. The analysis has been used to determine the composition of expired gas as a function of disease state, to obtain the arterial partial pressures of oxygen and carbon dioxide, and to derive the cardiac output using the indirect Fick principle. NASA has developed instruments for in-flight gas analysis. One of the first ones was a miniaturized double-focusing mass spectrometer<sup>25</sup>, weighing less than 50 pounds (equivalent commercial equipment weighs several hundred pounds). This device is capable of monitoring twelve gases simultaneously with a response time of 1/20 of a second and an accuracy of 3.5 per cent of full scale. The fast response is a very valuable feature since the last 1/10 of a second of a normal expiration will closely approximate the alveolar and, therefore, the arterial partial pressures of oxygen and carbon dioxide. A response time shorter than 1/10 of a second is therefore required. The instrument is also capable of continuously monitoring the partial pressure of several anesthetic gases, making it very valuable for use during surgery.

An oxygen consumption rate computing system<sup>26</sup> has been built under NASA sponsorship, which employs a quadrupole mass spectrometer and a gas flow-rate measuring system to compute the oxygen consumption. The system has a response time of 30 milliseconds and has been used to continuously monitor subjects at rest and during exercise. This device may prove very valuable in cardio-pulmonary exercise analysis.

Another miniaturized mass spectrometer<sup>27</sup> has been designed to fit under the chin of an astronaut inside his helmet. It will be used to monitor the change in oxygen, carbon dioxide, nitrogen, and water vapor between inspiration and expiration. The techniques used to develop the device may be applicable to the design of an analyzer for clinical or hospital use.

NASA has also funded work on the improvement of a photoionization mass spectrometer<sup>28</sup>. The contractor has decreased the intensity problem and therefore increased the chances of applying photoionization techniques to gas analysis. In certain applications a photoionization mass

spectrometer would be far less expensive than the presently used mass spectrometers.

Recently a complete electronic system called MIRACLE II<sup>29</sup> has been made available by NASA for automatic and instantaneous analysis of respiratory processes. This sophisticated system is capable of providing a quantitative analysis of the amounts of gases and the breathing patterns on a breath-by-breath or averaged basis. The extremely flexible and comprehensive analyzer should be valuable to researchers and physicians as an aid in understanding and diagnosing respiratory ailments.

### Respiratory Volume and Flow

In addition to analyzing a patient's oxygen consumption and expired gases, it is important to monitor the rate of flow and volume of gases inspired and expired. A device called the Wright spirometer has been modified<sup>30</sup> to produce digital electric output that can be processed by a computer, significantly reducing the work required for determining flow rate. In addition, the computer can be used to correct the data output for the nonlinearity of the calibration curve. Less than one-tenth volt is required for the spirometer, allowing the device to be powered by a self-contained battery. The instrument provides detailed data on respiratory volume and flow rate which can be of significant value to the physician or screening clinician.

Another similar instrument, known as a turbine flowmeter<sup>31</sup>, has been recently constructed also for monitoring flow rates and volume. It is extremely reliable and is better than 1/4% accurate over a range of 500 liters of air per minute. This accuracy should prove very worthwhile to the physician interested in precise quantitative analysis.

### Respiration Rate Monitoring

During surgery and in intensive care units, it is frequently important to carefully monitor a patient's respiratory rate. This information is a primary indicator of the patient's condition and it is vitally important to detect any sudden or unexpected changes in rate. NASA has developed two separate pneumotachometers<sup>32, 33</sup> which can be used to monitor a patient's respiration. The first of these uses

two rate-to-analog convertors to count respiration pulses from an impedance pneumograph body sensor. It is able to determine respiration rates in breaths per minute on a breath-to-breath basis.

The second instrument was designed for use on an astronaut undergoing a variety of activities. Previous monitors have not been reliable under conditions of noise, vibration, thermal disturbance, and subject activity. The NASA pneumotachometer uses a microphone in series with the astronaut's oxygen supply to detect the turbulent air caused by each breath. The device is particularly responsive to low-volume, slow breathing. It is also unaffected by motion and would be valuable in a clinic for monitoring a patient during exercise.

A very small nosepiece respiration monitor<sup>34</sup> has been designed to give a fast response without the uncomfortable and encumbering headgear or chestbands that have been used in the past. The system utilizes a heated thermistor which is alternately heated and cooled by the patient's exhalation and inhalation. The components are inexpensive and the output is compatible with conventional high impedance input devices. The respiration monitor would be valuable in monitoring hospital patients and, because of its cost, quite useful even in a physician's office. It is also well suited for monitoring a patient who has been severely burned since it involves a minimum amount of contact with the body.

Hospital patients sometimes need to have tracheostomy tubes surgically implanted in their windpipe to ease breathing difficulties. In the case of infants or comatose patients, there is a constant danger that the tube may become clogged and cause the individual to be suffocated before a nurse discovers the blockage. Even with constant surveillance, there is still a chance that the nurse could be distracted for the few minutes (2-4) it takes for brain damage to occur with a lack of oxygen. An automatic respiration failure detection system<sup>35</sup> has been designed and constructed by NASA. The system consists of a miniaturized sensor, amplifier, and transmitter which are attached to the tracheostomy tube and a receiver with an alarm system. The advantages of this system are the elimination of interconnecting wires through the use of telemetry, the miniature size of the detector, and the various failure modes recognized by the alarm control unit. An audible or visual alarm is actuated



if the respiration falls below a certain level or in case of system failure (including power failure). Preliminary testing has shown the monitor to be reliable and very useful. Approximately six monitors have been constructed and are in use throughout the country.

NASA's contributions to the field of respiratory monitoring have been substantial. They include sophisticated respiratory gas analysis, accurate monitoring of flow rates, and respiratory rate detection. The techniques and equipment involved are highly appropriate for use in hospital wards and in clinical screening facilities.

### 3.2.3 Electroencephalography

Electroencephalography (EEG) is the process of detecting and analyzing the electrical brain waves that are present at the surface of the scalp. NASA has developed electrodes and analytic equipment which are valuable to the researcher and practicing neurologist.

#### Electrodes

One of the greatest problems in EEG monitoring has always been the electrodes which must be attached to the scalp. Those used in the past were frequently irritating, difficult and time-consuming to attach, and short-lived. One of NASA's first solutions was the development of non-irritating sponge-like electrodes mounted inside a helmet<sup>36</sup>. The helmet is easy to put on and remove and contains a transmitter for the EEG signals so that the subject is not wired to an instrument and is therefore free to move. The transmitter uses miniature mercury cells capable of providing power for 90 hours of continuous operation. The helmet required only five minutes of initial fitting and the data obtained has been consistent with EEG records acquired with carefully applied metallic electrodes.

More recently, a lightweight cap containing two electrodes and a transmitter<sup>37</sup> has been developed. The cap is comfortable and the electrodes are non-irritating. The device is being clinically tested with the use of a computer as a means of diagnosis and treatment of schizophrenic mental patients. Because the cap is lightweight it is not frightening to disturbed patients. In addition, the absence of wires reduces the

subjects' anxiety about shock therapy if he is fearful of such treatment. The NASA researcher plans to develop an eight-channel transmitter capable of broadcasting over a 200-foot radius.

### EEG Analysis

Among the EEG analysis techniques devised by NASA, the most recent is an electronic sleep analyzer<sup>38</sup>. This instrument analyzes EEG waveforms and indicates in which of five levels of consciousness a patient may be. The levels are: awake, drowsy, light sleep, deep sleep, and abnormally slow (e.g., coma). The analyzer has the following advantages over previous devices:

- (1) Small size
- (2) Operational in real time
- (3) Minor effects from electrode or movement artifacts
- (4) Requires only one channel of EEG activity (central to occipital), and
- (5) Requires very little telemetry time or bandwidth.

The sleep analyzer should be valuable in research analysis of sleep.

### 3.2.4 Chemical Analysis

The equipment discussed in this section differs somewhat from the instruments previously mentioned in that they do not perform an instantaneous monitoring function as do EKG devices. However, they do provide accurate analysis in a matter of minutes as opposed to previous techniques that take much longer. Consequently the patient can be frequently monitored with a rapid response. Apparatus has been developed for the automatic analysis<sup>39, 40</sup> of a small sample of body fluids. Using flourimetry or colorimetry<sup>41</sup>, it quantitatively determines the amount of constituents such as calcium, creatine or creatinine present in a sample of only two to eight microliters. The only technician time required is for

loading the stock reagent solutions and sample fluid. Additional valuable features of the system are:

- (1) The small size and weight of the equipment make it practical for portable use,
- (2) Electrical readout adapts the device to data storage on tape or display, and
- (3) Automatic analysis make it attractive for clinical use because of the cost and time savings.

Another NASA invention is able to automatically detect and count bacteria present in urine samples<sup>42</sup> to determine the extent of possible infection. The high incidence of urinary tract infections together with the possibility that the infections are serious makes the analysis of urine one of the most frequently conducted tests in clinical laboratories. The present methods are highly time-consuming and not entirely satisfactory. The NASA device can accurately determine the presence of bacteria in biological specimens in only 30 minutes. This innovation should be valuable in hospitals and clinics for monitoring the infectious states of patients.

#### 3.2.5 Vision Testing

NASA had funded the development of several instruments that have research and clinical applications for monitoring the human eye. All of the devices are relatively new but show promise for revolutionary diagnostic techniques. The first device is called an oculometer<sup>43</sup>, which is capable of monitoring eye-pointing direction, pupil position, pupil diameter and blink occurrence. Eye angles can be determined to within  $1/5$  of a degree over a range of  $\pm 20$  degrees eye motion in both vertical and horizontal directions. The oculometer can tolerate head displacement of approximately  $\pm 2.5$  centimeters longitudinally and  $\pm 12$  centimeters laterally, and it is linear over a range of two to nine millimeters pupil diameter. Example applications are:

- (1) Reading analysis for performing studies of normal, abnormal, or new reading processes,
- (2) Mental alertness monitor, and
- (3) Psychological testing.

Another instrument, called the optometer<sup>44</sup> has been developed for NASA for studies on voluntary control of visual accommodation, that is, ability to focus and speed of focusing. It is the first objective measurement technique developed for the study of eye focusing that does not interfere with visual tasks. The optometer will produce new knowledge of the eye and will make possible the screening of school children with focusing defects.

An automated visual sensitivity tester<sup>45</sup> has been devised for monitoring astronaut's visual capabilities during long-term space missions. Among other tests, the instrument plots the subject's blind spot. Comparison of the plots over a period of time will indicate whether or not a visual problem exists (such as glaucoma). The tester could be very valuable if used for these tasks in a clinical screening facility.

### 3.2.6 Bone Density Measurement

An ultrasonic bone densitometer<sup>46</sup>, originally developed to determine bone degradation in weightless astronauts, is being tested for use on hospital patients. It is known that prolonged lack of exercise causes the bones to lose calcium and consequent strength. The loss is exhibited by a density change. Presently, x-rays are used to determine the change, but this presents some danger of overexposure to radiation. The ultrasonic tester is safe, simple, and less expensive than radiography. Presently, it is designed to be used on a finger or heel and can be adapted for easy use on bed patients. Other ultrasonic bone densitometers have been available, but this one has the following improvements:

- (1) Use of a bandpass amplifier to prevent the system from oscillating at the natural frequency of the transducers,

- (2) Use of a self-sustaining pulse circuitry to measure bone density in terms of a frequency change, thus resulting in increased resolution,
- (3) Special transducer composition covered with silicone rubber spacers for comfortable coupling, and,
- (4) Cylindrical focus elements for finger bones.

The densitometer may prove very useful for monitoring the bone condition of bed-ridden patients.

### 3.2.7 Radiation Probe

Radiation therapy to destroy cancerous cells can damage surrounding healthy tissue. Consequently, radiologists have been in need of a miniaturized device to monitor radiation exposure in tissue. NASA has funded the development of a tiny radiation probe<sup>47</sup> which has filled the requirements. The semiconductor probe will enable radiologists to control treatment with increased precision, thereby making the process safer for the patient.

### 3.2.8 Intragastric Monitoring System

A NASA system under development is capable of monitoring intragastric physiological functions<sup>48</sup> over periods of time exceeding two weeks. Previous to this system, long term monitoring was impossible in freely ranging patients.

The equipment consists of a tethered sensor capsule (approximately one inch long, 3/8 inch in diameter), automatic titration unit, telemetry unit, and data display. Signal relay from the capsule is via hardline to the multichannel telemetry unit on the subject's body, and then by RF transmission to a central receiving station for storage and display. The system measures pH ( $\pm .2$  pH over range of 1 to 10 pH), temperature ( $\pm .2^{\circ}\text{C}$  over range of  $25^{\circ}\text{C}$  to  $45^{\circ}\text{C}$ ) and pressure ( $\pm 10\%$  over pressure range of 0 to 15 inches of water). Preliminary tests have shown a useful capsule life of approximately 30 days. Another innovation has been the in vivo calibration and completion of several experiments.

The system should provide a revolutionary means of monitoring patients with chronic gastric disorders.

NASA has had numerous contributions to the monitoring of specific physiological functions. A large portion of the equipment and apparatus is applicable to cardiovascular monitoring. This result is quite appropriate because the condition of the cardiovascular system is so crucial to the health of a patient. NASA research and development has resulted in innovations in EKG, blood pressure, blood flow, heart rate, and heart sounds monitoring. The equipment has demonstrated, and will continue to demonstrate, its value in the coronary care unit, the intensive care unit, in surgery, and in post-operative recovery.

There have also been significant NASA innovations to the monitoring of other physiological parameters, such as EEG, visual accommodation, tracking and blindness, bone density, chemical and bacteria composition, radiation, and respiratory rate, gas, and flow. The value of the instruments for monitoring these parameters should not be underestimated. Many of them are highly innovative and will undoubtedly assist a great deal in increasing the knowledge of bodily functions.

### 3.3 Other NASA Contributions to Patient Monitoring

NASA has funded several projects which have definite application to patient monitoring, but they do not fall into specific categories of physiological function because they are more generally oriented. This section describes some of the work which has been done.

#### 3.3.1 Automated Patient Monitor

A wireless patient monitoring system<sup>49</sup> has been developed under a NASA contract and is capable of monitoring several physiological functions from as many as 64 patients. The equipment consists of battery-powered transmitter units for each patient and a central receiving station which monitors the functions. The patient unit weighs less than one pound, resulting in a minimum of discomfort. The previous patient monitoring systems used different frequencies to transmit each of the patient's parameters. NASA's system uses only one frequency with FM pulse code modulation to minimize electrical or radio

interference of the data. The individual patient units do not transmit information unless addressed by the central receiving station. Consequently, a patient may have only a few functions monitored routinely or several functions monitored frequently, depending on his condition. Conventional transducers for detecting physiological functions are compatible with the patient units.

### 3.3.2 Self Testing and Repairing Computer

Possible failure of conventional monitoring systems and the consequences that may result have caused hospitals to be hesitant in relying on their use. A new computer system capable of repairing itself<sup>50</sup> has been developed for use in prolonged interplanetary space probes. The prototype system presently under construction is the only practical hardware in existence. The concepts used in the design could readily be applied to the development of a computerized patient monitoring system that would be extremely reliable. Such a system would be very advantageous in the intensive care unit, where patients must be monitored constantly.

### 3.3.3 Biotelemetry

Biotelemetry is the monitoring of biological functions in a remote location, with wireless transmission to another location. NASA has been deeply involved with biotelemetry because of the requirement for monitoring the physiological functions of the astronauts. For example, while the Apollo crew worked on the surface of the moon, doctors at the Manned Spacecraft Center were observing the astronauts' electrocardiograms. This feat of technology is only an example of the expertise that NASA scientists have developed in the field of biomedical telemetry. Wireless transmission can be useful in the hospital environment because it places no restrictions on the patient's movement and because it can assure the absence of potential electrical shocks to the patient. Many miniaturized amplifiers and transmitters<sup>51</sup> have been designed and tested at the Ames Research Center. A large number of these have been used in practical applications by physicians and technicians outside of NASA.

However, these examples really do not do justice to the innovations which NASA has made. Because of the large amount of NASA research and development in biotelemetry for in-flight monitoring of astronauts, NASA work can provide a stimulus for the development of telemetry equipment to be used for patient monitoring.

Example possibilities for the use of telemetry in patient monitoring are:

- (1) To monitor exercising subjects in order to obtain information on the response of the cardiopulmonary system to exercise. With knowledge of a "normal" response it would be possible to monitor patients to obtain warnings of diseases in their early stages.
- (2) To conveniently monitor patients in remote areas. For example, it would be possible to perform complex monitoring of a patient in a location where there was no hospital if his physiological functions could be telemetered to a clinic or hospital for observation.
- (3) To perform long-term internal monitoring of a patient when it is not safe or practical to have wires passing from inside his body to an outside receiver.

#### 3.3.4 Integrated Material and Behavioral Laboratory Measurement System

NASA is developing the Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS)<sup>52</sup> to perform medical research during extended manned space flights. The system will be used to perform comprehensive medical and behavioral measurements on board the spacecraft and will process, store, display and transmit the resulting data. The flexibility of the design will allow IMBLMS to be used for a variety of missions far into the future. The system is in such early stages of development that it is impossible to give specifications for the equipment. However a list of the measurements which IMBLMS is intended to handle is given in the list on the following three pages. The measurements list displays the magnitude and scope of IMBLMS.

Because IMBLMS has such broad coverage and will be used to monitor so many physiological functions, it would appear to have great potential for patient monitoring. The techniques used for IMBLMS may be used to significantly advance the state-of-the-art in present day monitoring equipment.



## MEASUREMENTS LIST FOR IMBLMS

### Neurological

Electroencephalogram	Visual Field Mapping
Electromyogram	Absolute Brightness Threshold
Electrooculogram	Critical Fusion Frequency
Galvanic Skin Response	Phorias
Ocular Counterrolling	Visual Acuity
Agravic Perception	Dark Adaptation
Semicircular Canal Threshold	Photo Stress
Angular Acceleration Threshold	Color Perception
Visual Task w/Head Rotation	Absolute Auditory Threshold
Coriolic Sickness Susceptibility	Speech Intelligibility
Depth Perception	Temporal Acuity
Brightness Threshold Discrimination	Pitch Discrimination

### Cardiovascular

Electrocardiogram	Heart Rate
Vectorcardiogram	Arterial Blood Pressure
Venous Blood Pressure	Pulse Wave Velocity
Limb Plethysmography	Pulse Wave Contour
Phono/Vibrocardiogram	Ballistocardiogram
Impedance Cardiogram	

### Respiratory

Respiratory Rate	Alveolar pO <sub>2</sub>
Vital Capacity	Alveolar pCO <sub>2</sub>
Timed Vital Capacity	Respiratory Dead Space
Inspiratory Capacity	Alveolar Ventilation
Expiratory Reserve Volume	Residual Volume
Tidal Volume	Airway Resistance
Minute Tidal Volume	Lung Compliance
Maximum Inspiratory Flow	Cardiac Output
Maximum Expiratory Flow	O <sub>2</sub> Consumption, CO <sub>2</sub> Production
Maximum Breathing Capacity	Lung Diffusion Capacity

## Laboratory Analysis

### (Blood)

Hemaglobin  
Hematocrit  
pH  
pCO<sub>2</sub>  
RBC Count  
WBC Count  
WBC Differential  
Platelets  
Reticulocyte Count

RBC Fragility  
RBC Mass  
Bleeding Time  
Clotting Time  
RBC Survival  
RBC Morphology  
Clot Retraction  
pO<sub>2</sub>

### (Plasma)

Sodium  
Potassium  
Chloride  
Calcium  
Protein  
Glucose

Phosphate  
Volume  
SGOT  
SGPT  
Alkaline Phosphatase  
Bilirubin

### (Urine)

Color  
Volume  
Specific Gravity  
pH  
Glucose  
Protein  
Bile  
Blood

Microscopic  
Calcium  
Phosphate  
Sodium  
Potassium  
Chloride  
Acetone Bodies

### (Miscellaneous)

Total Body Water

## Microbiology

Bacteria and Fungi

Virus

## Metabolic

Ear Canal Temperature  
O<sub>2</sub> Consumption, CO<sub>2</sub> Production  
Average Skin Temperature

Muscle Strength and Size  
Body Mass and Specimen Mass  
Balance Studies

### Behavioral

Time and Motion  
Concentration  
Pressure Threshold  
Tracking

Multilimb Coordination  
Steadiness  
Reaction Time

### Environmental

Atmospheric Pressure  
Atmospheric Composition  
Temperature, Humidity

Spacecraft Motion  
Noise  
Radiation

### 3.3.5 Medical Information Computer Systems (MEDICS)

The previously discussed project called IMBLMS is part of a more extensive NASA program known as MEDICS.<sup>53</sup> The major objectives of MEDICS are:

- (1) Improvement of data acquisition capabilities for operational and experimental use.
- (2) Improvement of descriptive inferential and predictive capabilities for both safety monitoring and research.
- (3) Improvement of standardization accuracy, consolidation, and interpretability of all medical data.

The program is comprised of five computer systems. In addition to IMBLMS, they are: Biomedical data acquisition and display system, biomedical monitoring system, clinical laboratory computer system, and stress physiology computer system. The entire program may produce significant contributions to patient monitoring and hospital information systems.

#### 4.0 TRANSFER SUMMARY

The purpose of this section is to present a brief overview of the purpose of NASA technology transfer as it relates to patient monitoring. A transfer is defined as the adoption of a NASA technique or instrument to solve a non-NASA problem. There are several ways in which a transfer may occur. First, a firm contracted by NASA to design and construct a piece of equipment may later acquire a license to produce it commercially. A second type of transfer occurs when an individual or manufacturer learns of a device through a journal or other literature and inquires about using it or obtaining a license to produce it. In addition, NASA has endeavored to take an active role in the implementation of transfers. The Technology Utilization Division (TUD) was formed specifically to assist in expeditiously transferring NASA technology to the scientific and industrial community. TUD has engaged in an extensive publications program in order to disseminate information. In the area of biology and medicine, TUD has also established three Biomedical Application Teams whose purpose is to actively engage in the process of technology transfer. These teams are located at the Midwest Research Institute, Research Triangle Institute and Southwest Research Institute. The team members communicate with researchers and clinicians at medical institutions to directly assist in solving biological and medical problems.

Table 4-1 contains a list of the TUD published Tech Briefs which are relevant to bioinstrumentation. The list has been broken into sections according to physiological function, with separate sections on biotelemetry and miscellaneous equipment. Tech Briefs are circulated among thousands of subscribers. There is usually a Technical Support Package available as backup material for the Tech Brief, which can be obtained by contacting the NASA center from which the Tech Brief originated. Table 4-1 also indicates the number of TSP's requested for each Tech Brief. More TSP's were requested on biotelemetry equipment than on any other group. This phenomenon can be explained by the fact that NASA has developed extremely sophisticated telemetry systems as a result of the requirements for remote commun-

ications and monitoring. However, if only physiological functions are considered, by far the most TSP's were requested in the area of cardiovascular monitoring and analysis. This large number of requests occurred for two reasons: first, there is an urgent need to provide better cardiovascular monitoring of critically ill patients and of patients undergoing clinical screening, and second, NASA has done a great deal of work on cardiovascular monitoring because of the intense interest in understanding and monitoring cardiovascular functions of astronauts performing tasks under weightless and other special conditions.

It should be noted that the numbers in Table 4-1 are somewhat low because a substantial number of TSP's are given out by means other than the normal procedure of requests made to the centers; consequently, the numbers given may be only one-half to three-fourths of the actual total.

Table 4-2 contains the responses of TSP requestors to whom questionnaires were sent by the Denver Research Institute. Questionnaires were sent to approximately 50% of the requestors, of whom almost 80% replied. Combined with the fact that only about 50% of the actual requestors are known to the Denver Research Institute, this means that the replies represent 20% to 30% of the individuals who actually obtain TSP's. The answers given in the table represent the extent to which the TSP's were used. Of the 8 Tech Briefs listed in the table,\* 4% of the responses indicated that the TSP's had stimulated research, and 46% indicated that it had helped to improve existing processes or products. In other words, 50% of the sampled requestors had made valuable use of the information. This is concrete evidence that NASA technology has provided substantial assistance to the medical world.

Table 4-3 contains summary information on user and manufacturer transfers that are discussed in Appendix A. The information on the transfers was compiled from BA Team reports and Denver Research Institute contact reports. Only a small number of the persons who responded positively to the questionnaires were contacted, with the result that the total number in Table 4-3 is much smaller than the total of positive responses in Table 4-2.

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\*Questionnaire information was available for the 8 Tech Briefs only.

In Table 4-3, Planned Use or Planned Manufacture means that the individual or company is in the process of using the NASA technology, or has definite plans of using it upon the receipt of expected development funds. Successful Use or Successful Manufacture means that the technology has already been successfully incorporated into an existing or newly developed instrument.

The transfer information contained in this report is by necessity a sampling of all the transfers that have occurred. However, the sample is extremely impressive: over 2,500 documented TSP requests, 50% of the requestors who returned questionnaires indicated that the TSP had been of significant use, with 103 known transfers having been accomplished.

TABLE 4-1

Bioinstrumentation Tech Briefs and the Number of  
Requestors for Technical Support Packages

<u>Tech Brief Number</u>	<u>Tech Brief Title</u>	<u>Number of Requestors for TSP's</u>
I. CARDIOVASCULAR MONITORING AND ANALYSIS		
B64-10025	Improved Electrode Gives High-Quality Biological Recordings	11
B64-10258	Digital Cardiometer Computes and Displays Heart-beat Rate	8
B65-10010	Inexpensive, Stable Circuit Measures Heart Rate	10
B65-10142	Auxiliary Circuit Enables Automatic Monitoring of EKG's	4
B65-10143	Digital-Output Cardiometer Measures Rapid Changes in Heartbeat Rate	4
B65-10320	Rugged Pressed Disk Electrode Has Low Contact Potential	4
B65-10325	Direct Force-Measuring Transducer Used in Blood Pressure Research	2
B66-10049	Improved Electrode Paste Provides Reliable Measurement of Galvanic Skin Response	4
B66-10088	Gelatin-Coated Electrodes Allow Prolonged Bioelectronic Measurements	7
B66-10118	Integral Skin Electrode for Electrocardiography is Expendible	7
B66-10154	Phonocardiograph System Monitors Heart Sounds	29
B66-10649	Spray-On Electrodes Enable ECG Monitoring of Physically Active Subjects	93
B67-10239	A Phonocardiogram Simulator	89
B67-10475	Blood Pressure Reprogramming Adapter Assists Signal Recording	3
B67-10598	Cardiometer with Linear Beat-to-Beat Frequency Response	111
B67-10669	Ultraminiature Manometer-Tipped Cardiac Catheter	151
B68-10144	Cardiac R-Wave Detector	55
B68-10220	New Electrical Impedance Plethysmograph Monitors Cardiac Output	65
B68-10233	Electrocardiograph Transmitted by RF and Telephone Links in Emergency Situations	54
B68-10563	Pressure-Sensitive Bonded Junction Transducers	7
B69-10598	Quick Don-Off Electrode Pastes	16



TABLE 4-1(Cont'd.)

<u>Tech Brief Number</u>	<u>Tech Brief Title</u>	<u>Number of Requestors for TSP's</u>
B69-10690	Miniature Backward-Diode Pressure Sensor Features Stability and Low Power Consumption	0
B70-10030	Contourograph Display System for Monitoring Elec- trocardiograms	8
B70-10420	Ultra-Flexible Biomedical Electrodes and Wires	27
<b>II. RESPIRATORY ANALYSIS</b>		<u>TOTAL 769</u>
B64-10259	Pneumotachometer Counts Respiration Rate of Human Subject	7
B65-10369	Respiratory Transfer Valve Has Fail-Safe Feature	3
B68-10188	High- and Low-Pressure Pneumotachometers Measure Respiration Rates Accurately in Adverse Environments	5
B68-10365	Automatic Patient Respiration Failure Detection System with Wireless Transmission	56
B68-10438	Nosepiece Respiration Monitor	15
B69-10319	Miniature Oxygen Resuscitator	5
B70-10402	Improved Photoionization Mass Spectrometer	0
B70-10528	Technique for Analyzing Human Respiratory Process	24
<b>III. ELECTROENCEPHALOGRAPHY</b>		<u>TOTAL 115</u>
B66-10536	Helmet System Broadcasts Electroencephalograms of Wearer	129
B70-10110	Electronic Sleep Analyzer	11
<b>IV. CHEMICAL ANALYSIS</b>		<u>TOTAL 140</u>
B66-10515	Apparatus Enables Automatic Microanalysis of Body Fluids	45
B67-10245	Automated Urinalysis Technique Determines Concen- tration of Creatine and Creatinine by Colorimetry	15
<b>V. VISION TESTING</b>		<u>TOTAL 60</u>
B68-10206	Infrared Viewing Would Permit Human Iris Response Studies	17
B69-10444	Oculometer for Remote Tracking of Eye Movement	0
		<u>TOTAL 17</u>

TABLE 4-1 (Cont'd.)

<u>Tech Brief Number</u>	<u>Tech Brief Title</u>	<u>Number of Requestors for TSP's</u>
VI. TEMPERATURE TELEMETRY		
B66-10057	Miniature Bioelectronic Device Accurately Measures and Telemeters Temperature	282
	<u>TOTAL</u>	<u>282</u>
VII. BONE DENSITY MEASUREMENT		
B68-10140	In instrumentation for Bone Density Measurement	7
	<u>TOTAL</u>	<u>7</u>
VIII. DOSIMETRY		
B66-10252	Semiconductor Forms Biomedical Radiation Probe	2
B68-10426	Ceric and Ferrous Dosimeters Show Precision for 50 - 5000 Rad Range	0
	<u>TOTAL</u>	<u>2</u>
IX. BIOTELEMETRY		
B64-10171	Subminiature Biotelemetry Unit Permits Remote Phys- iological Investigations	292
B66-10624	Miniature Telemetry System Accurately Measures Pressure	157
B68-10065	Multichannel Implantable Telemetry System	195
B69-10117	Remotely-Actuated Biomedical Switch	9
B69-10312	New Passive Telemetry System	11
B70-10079	Telemetry for Impact Acceleration Measurements	7
	<u>TOTAL</u>	<u>671</u>
X. MISCELLANEOUS		
B63-10003	New Low-Level A-C Amplifier Provides Adjustable Noise Cancellation and Automatic Temperature Compensation	10
B65-10079	Photoelectric Sensor Output Controlled by Eyeball Move- ments	20
B65-10091	Simulator Produces Physiological Waveforms	8
B65-10203	Tiny Biomedical Amplifier Combines High Performance, Low Power Drain	177
B66-10534	Miniature Piezoelectric Triaxial Accelerometer Measures Cranial Accelerations	40
B66-10549	Miniature Electrometer Preamplifier Effectively Compensates for Input Capacitance	105

TABLE 4-1 (Cont'd.)

<u>Tech Brief Number</u>	<u>Tech Brief Title</u>	<u>Number of Requestors for TSP's</u>
B67-10076	Cleanroom Air Sampler Counts, Categorizes, and Records Particle Data	115
B67-10369	Multiple Meter Monitoring Circuits Served by Single Alarm	4
B67-10663	Review of Biological Mechanisms for Application to Instrument Design	50
B68-10131	Automated Patient Monitoring System	51
B68-10174	Low Scatter Lightweight Fission Spectrometer Con- structed for Biological Research	0
B69-10088	Microscopes and Computers Combined for Analysis of Chromosomes	0
B69-10224	Two Devices for Analysis of Nystagmus	2
B69-10294	Mass Culture of Photobacteria to Obtain Luciferase	0
B69-10385	Improved Perceptual-Motor Performance Measurement System	7
B69-10720	Biomedical Bulk Data Processing Program	0
B70-10107	Detection and Location of Metal Fragments in the Human Body	19
B70-10348	Electromechanical Hand Incorporates Touch Sensors and Trigger Function	4
B70-10452	Self Testing and Repairing Computer: A Concept	2
B70-10508	Log Amplifier Instrument Measures Physiological Bio- potentials Over Wide Dynamic Range	
	<u>TOTAL</u>	<u>614</u>
<u>TOTAL OF ALL REQUESTORS</u>		<u>2677</u>

Table 4-2

RESPONSE TO D.R.I. QUESTIONNAIRESCardiovascular

68-10233  
Electrocardiograph Transmitted by RF and Telephone Links in Emergency Situations

66-10649  
Spray-On Electrodes Enable ECG Monitoring of Physically Active Subjects

67-10669  
Ultraminiature Manometer-Tipped Cardiac Cathometer

Biotelemetry

64-10171  
Subminiature Biotelemetry Unit Permits Remote Physiological Investigations

65-10203  
Tiny Biomedical Amplifier Combines High Performance, Low Power Drain

66-10057  
Miniature Bioelectronic Device Accurately Measures and Telemeters Temperature

66-10624  
Miniature Telemetry System Accurately Measures Pressure

68-10065  
Multichannel Implantable Telemetry System

	No beneficial results or helped keep requester abreast of developments in field of interest	Stimulated basic and applied research	Improved existing process(es) or technique(s)	Developed new process(es) or technique(s) and Developed new products	Improved existing product(s) and Reduced operating costs
	3		1	1	1
	24		8		3
	26	2	12		2
	64	5	34	1	27
	37	3	28	1	10
	42	2	28	1	23
	28	4	15		12
	10	1	3		3

TOTALS

234 17 129 4 81

Percent of Grand Total

50 4 28 1 17

Table 4-3

Transfers to Users and Manufacturers				
Area	Planned Use	Successful Use	Planned Manufacture	Successful Manufacture
Cardiovascular	1	23	1	6
Respiratory	2	4	1	
Electroencephalography	3	3		
Visual			1	
Radiation Detection	2			1
Biotelemetry	10	23	1	5
General Patient Monitoring	2	1		3
Miscellaneous	3	7		
TOTAL	23	61	4	15

APPENDIX A  
PATIENT MONITORING BACKUP  
MATERIAL AND TRANSFERS

## APPENDIX A: PATIENT MONITORING BACKUP MATERIAL AND TRANSFERS

Appendix A contains backup material on all of the items referenced from Chapter 3. Each reference has a title identical to the name used in the chapter. If there is a Tech Brief involved, it is listed first followed by any articles related to it. The next section consists of user information. Although it may not all be available, the information will consist of: number of requests for Technical Support Packages by year, results of a questionnaire sent out by the Denver Research Institute on the use of the Technical Support Package, and finally information on the uses that have been made of the NASA device. The requests by year and the questionnaire results were obtained from the Denver Research Institute. The transfer information was obtained from the Biomedical Application Team reports and Denver Research Institute case files.

The last group of information (when it is available) contains the names of firms that are manufacturing instruments as a result of the NASA innovation. This information was also obtained from the Denver Research Institute case files.

1. ELECTRODES AT MSC

Tech Briefs:

- |           |  |
|-----------|--|
| B64-10025 | Improved Electrode Gives High-Quality Biological Recording                           |
| Source:   | M. W. Lippitt and J. L. Day, NASA  |
| B65-10015 | Improved Conductive Paste Secures Biomedical Electrodes                              |
| Source:   | Baylor University, under contract to MSC   |
| B65-10320 | Rugged Pressed Disk Electrode Has Low Contact Potential                              |
| Source:   | J. L. Day, NASA, and Institute of Research and Instrumentation under contract to MSC |
| B66-10049 | Improved Electrode Paste Provides Reliable Measurement of Galvanic Skin Response     |
| Source:   | J. L. Day, NASA  |
| B66-10088 | Gelatin-Coated Electrodes Allow Prolonged Bio-electronic Measurements                |
| Source:   | Institute of Research and Instrumentation, under contract to MSC                     |
| B66-10118 | Integral Skin Electrode for Electrocardiography is Expendable                        |
| Source:   | North American Aviation Inc., under contract to MSC                                  |
| B69-10598 | Quick Don-Off Electrode Pastes   |
| Source:   | Dr. Benjamin Mosier of Institute of Research, Inc.                                   |

Articles and Papers:

- 1 Montes, L.F., J. L. Day and Lofton Kennedy, "The Response of Human Skin to Long-Term Space Flight Electrodes," Journal of Investigative Dermatology, Volume 49, No. 1.
- 2 Day, J. L., "Review of NASA-MSC Electroencephalogram and Electrocardiogram Electrode System Including Application Techniques", NASA Technical Note D-4398, April 1968.
- 3 Day, J. L., L. F. Montes, and B. Mosier, "The Evolution of Long-Term Electrode Systems Suitable for Electrocardiography



and Electroencephalography on Manned Space Flight". Unpublished paper at MSC, reprints from J. L. Day

- 4 Day, J. L. and M. W. Lippitt, "A Long-Term Electrode System for Electrocardiography and Impedance Pneumography", NASA-MSC, reprints from J. L. Day

User Information:

From J. L. Day's (co-inventor of electrodes and electrode pastes at MSC) correspondence:

4/19/68

Dr. C. C. Lushbough of Oak Ridge Associative University claimed a set of electrodes obtained from MSC out-performed Beckman electrodes.

5/9/68

Dr. William P. Blocker, Jr., of the Veterans Administration Hospital in Houston said that Day's electrode paste is valuable in prolonged monitoring because "it is non-sensitizing, non-irritating, and slow to dry out."

12/3/69

Dr. Runge of the Department of Pathology of the University of Minnesota said that excellent results could be obtained for ECG and EEG by using Day's Silver/Silver Chloride electrodes and dye-marked electrode jelly.

1/16/70

Dr. Bert S. Kopell of Stanford University Medical Center requested a set of Day's electrodes because he had been told by Dr. Frederick Delse that they were superior to all others available.

## 2. SPRAY-ON ELECTRODES

### Tech Brief:

B66-10649    Spray-On Electrodes Enable ECG Monitoring  
of Physically Active Subjects

Source:        Flight Research Center

### Articles and Papers:

- 1 Patten, Charles W. and Frank B. Ramme of Spacelabs, Inc.  
and James Roman of NASA-FRC  
"Dry Electrodes for Physiological Monitoring"  
NASA Technical Note D-3414, May 1966.
- 2 Trank, J., R. Fetter, and R.M. Lauer, "A Spray-On Elec-  
trode for Recording the Electrocardiogram During Exercise,"  
Journal of Applied Physiology, Vol. 24, No. 2, Feb. 1968.

### User Information:

#### Requests for Technical Support Packages by Year:

<u>1967</u>	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>Total</u>
45	30	7	11	93

### D. R. I. Questionnaire Results:

Out of 35 questionnaires returned:

8 replies stated that the TSP had "improved existing processes  
or techniques"

3 replies stated that the TSP had "improved existing products  
or reduced operating costs."

### Transfers:

- 1 A pediatric cardiologist who was having difficulty obtaining  
accurate electrocardiograms on children under exercise  
conditions, found that the spray-on electrode technique devel-  
oped at the NASA Flight Research Center successfully alle-  
viated the variations in electrical contact having a detrimental  
effect on EKG signals. The NASA technique has proven success-  
ful in all 1,000 children tested, and a commercial version  
of the electrode has been introduced.

- 2 Dr. Robert Schwitzgebal at Claremont Graduate School, Claremont College, California, contacted the Southwest Research Institute for help in a feasibility study of employing electro-mechanical means (GSR) for modifying the behavior of adolescent delinquents interacting in the school setting. Researchers were concerned that the electrodes be as unobtrusive as possible so as not to disrupt the child's activity or cause him to be ostracized by his peers.

SwRI performed a preliminary search of the NASA literature, and found the NASA-developed method of spray-on electrodes to be well-suited for the active subject (non-injurious, non-irritating), in addition to being reliable and highly efficient.

- 3 Dr. Sanford Topham of the University of Utah requested a technology transfer from a BATeam with regard to the use of electrodes on dogs being measured for heart rate while on a treadmill. The main problems encountered were due to the activity of the dogs either producing motion artifacts or tearing the electrodes away from the skin. The spray-on electrodes developed at the NASA Flight Research Center, proved to meet the requirements outlined by the researcher. The method is rapid, well suited to the active subject, and results neither in bulk nor significant discomfort. The major benefits of the technique are increased reliability (minimized motor artifacts) and data gathering efficiency.
- 4 Dr. Ronald Lauer at the University of Kansas Medical Center evaluated the NASA spray-on electrode technique through extensive experimentation with active children. M.R.I. reports that Dr. Lauer's group found spray-on electrodes to be advantageous due to ease of application, freedom from motion artifact, little tendency to come loose during exercise, and cost-effectiveness.
- 5 Hauser Research and Engineering Company produced a commercial version of spray-on electrodes, which has been evaluated at the University of Kansas Medical Center. The first units were found to be unsatisfactory because of dripping and clogging; however, the Hauser Company modified the units, which have proven satisfactory through subsequent testing.
- 6 PATT reports that researchers at a Pennsylvania laboratory plan to use the spray-on electrodes developed by the NASA Flight Research Center, to monitor cardiovascular functions in dogs and monkeys while testing new anti-hypertension drugs. Present practice entails anesthetizing the animals and inserting wires with a consequent danger of infection. External electrodes should prove to be much simpler and less dangerous.

### Information on Manufacturers

Precision Electro-Mechanical Engineering Co.  
421 West Avenue I  
Lancaster, California 93534

Precision Electro-Mechanical Engineering Co. has recently designed an adapter for the spray gun so that EEG electrodes may be made also. Recently the firm merged with Space Age Controls, and efforts are underway to contract with another firm for an aggressive marketing relationship.

Hauser Research and Engineering Co.  
P. O. Box G  
2965 Peak Avenue  
Boulder, Colorado

As a sub-contractor to NASA, Hauser Research developed a spray-on conductive electrode adhesive for FRC. The advantages of the spray-on ECG electrode are those of rapid application, durability, and freedom from motion effects. Hauser's \$39 kit contains aerosol sprays of the conductive adhesive, and insulating over-spray to prevent effects from clothing contact, an ECG remover, spray controller and electrode wires.

### 3. FLEXIBLE ELECTRODES AND WIRES

#### Tech Brief:

B70-10420 Ultra-Flexible Biomedical Electrodes and Wires

Source: S. A. Rositano, Ames Research Center

Technical Support Package is available.

#### Transfer

Dr. Gerald Glick of Baylor University College of Medicine needed a biologically inert, soft, flexible conducting electrode for use in establishing an electrical connection between the surgically exposed carotid sinus nerve and a lead from an implanted cardiac pacemaker. A pair of rigid platinum electrodes in silicone rubber foam was previously used and proved to be both dangerous and ineffective. The SwRI team conducted an extensive search which resulted in the development of an inert, flexible electrode which would provide an effective electrical connection between the nerve and a lead from an implanted cardiac pacemaker. NASA's willingness to improve the flexible electrode is expected to significantly advance ongoing research.

#### 4. EKG ELECTRODE HARNESS

Rapid Application of Electrocardiographic Electrode and Pre-cordial Harness, M. Weisberg, R. White, W. Miller, J. Landoll, W. Ayres, and W. Chen.

Work performed under summer study program at Goddard Space Flight Center.

#### 5. CONTOUROGRAPH DISPLAY SYSTEM

##### Tech Brief:

B70-10030 Contourograph Display System for Monitoring Electrocardiograms

Source: D. P. Golden, D. G. Maudlin, and R. A. Wolthiers of Technology Incorporated under contract to MSC.

Technical Support Package is available.

##### Articles and Papers:

Golden, D. P., G. Maudlin, and R. A. Wolthiers, "Real Time Cardiography - An Improved Electrocardiographic Display", IEEE Transactions on Biomedical Engineering, October 1970.

#### 6. AMBULANCE EKG TRANSMISSION SYSTEM

##### Tech Brief:

B68-10233 Electrocardiograph Transmitted by RF and Telephone Links in Emergency Situations

Source: C. E. Lewis, L. R. Carpenter, and R. T. MacDonald of the Flight Research Center

##### User Information:

##### Requests for Technical Support Packages by Year:

<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>Total</u>
30	19	5	54

#### D. R. I. Questionnaire Results

Out of 6 questionnaires returned:

1 reply stated that the TSP had "developed new processes or techniques and a new product"

1 reply stated that the TSP had "improved existing processes or techniques"

1 reply stated that the TSP had "improved existing products and reduced operating costs"

#### Transfers:

- 1 In a news release from the Mt. Zion Hospital in San Francisco, California, Dr. Herman Uhley reported that the hospital's coronary unit can now diagnose the acuteness of an attack by monitoring patient heartbeats from an ambulance via radio, and thus prepare for appropriate treatment.
- 2 The largest installation in the United States of an EKG transmission system is located in San Francisco. In addition to Mt. Zion Hospital, the system has been installed at Antelope Valley Hospital and Antelope Valley ambulances with great success.
- 3 NASA Flight Research Center reports that the Schaefer Air-Ground Ambulance Service in Los Angeles, which has been operating for 32 years and now includes a fleet of 46 ambulances and several ambulance helicopters, is testing the EKG transmission system.

The Company handles approximately 75,000 emergency cases annually, and about 300 cardiac patients per month. Schaefer's Ambulance Service learned of the new technique through NASA's Technology Utilization Program.

#### Information on Manufacturer:

Electro-Biometrics, Inc.  
46205 North Division Street  
Lancaster, California 93534

Mt. Zion Hospital equipped its seven ambulances with the EKG transmission system designed by Electro-Biometrics, Inc. A proposal by two doctors at the University of California Medical Center resulted in the preliminary adoption of the system by San Francisco municipal ambulances, pending affirmation by City Hall.

## 7. FOUR ELECTRODE IMPEDANCE PLETHYSMOGRAPH

### Tech Brief:

B68-10220      New Electrical Impedance Plethysmograph  
Monitors Cardiac Output

Source:          W.G. Kubicek, R.P. Patterson and D.A. Witsoe  
of the University of Minnesota under contract  
to MSC

### Reports:

- 1 Kubicek, W.G., J.N. Karnegis, R.P. Patterson, D.A. Witsoe, and R.H. Mattson, "Development and Evaluation of an Impedance Cardiac Output System", Aerospace Medicine, Vol. 37, No. 12, December 1966
- 2 Kubicek, W.G., D.A. Witsoe, R.P. Patterson, M.A. Mosharrofa, J.N. Karnegis and A.H.L. From, "Development and Evaluation of an Impedance Cardiographic System to Measure Cardiac Output", Final Report under Contract to MSC, July 1967
- 3 Technical Support Package is also available

### Transfers

- 1 A research team headed by Dr. Marvin Pomerantz at the Denver General Hospital and the University of Colorado Medical School, has developed a new use for a four electrode impedance plethysmograph developed under contract to NASA's Manned Spacecraft Center. After successful laboratory use, the instrument is being used in clinical applications. The new instrument has several advantages, including greater stability and a considerably better electrode system. The primary clinical use of the instrument is as a warning indicator of the onset of edema, allowing immediate remedial treatment.
- 2 Dr. C. Walston Lielehei of New York Hospital believes that the impedance plethysmograph device can probably detect an acute rejection crisis faster and more reliably than can ECG voltages. Only at New York Hospital and Cape Town's Groote Schuur Hospital is the device reportedly being used on transplant patients. A recent NASA meeting on the cardiac device uncovered reports of the utilization of the plethysmograph in the diagnosis of angina, coronary occlusion, and heart failure.

8. IMPLANTABLE MINIATURE ULTRASONIC SONOMICROMETER

No tech brief available to date

Work performed by Robert D. Lee and Harold Snadler at the Ames Research Center.

Papers and Articles:

- 1 Lee, Robert D. And Harold Sandler, "Miniature Implantable Sonomicrometer System", report from Ames Research Center. (reprints from R. D. Lee).
- 2 Lee, Robert D. and Harold Sandler, "Miniature Implantable Sonomicrometer System", Journal of Applied Physiology, Vol. 28, No. 1, January 1970.

9. HEART SOUND MICROPHONE

Developed under summer program at Goddard Space Flight Center by: A. Lipschultz, P. Turer, H. Wannemacher, D. Lee, W. Ayers, and W. Chen.

10. HEART SOUND PREPROCESSOR

Developed under summer program at Goddard Space Glight Center by: R. Martino, M. Hooshmand, W. Olden, D. Winer, M. Wilbur, W. Ayers, W. Chen.

11. VIBROCARDIOGRAM TRANSDUCER

There is no Tech Brief Available

Developed under contract to Ling Temco Vought, Inc., and the Institute for Medical Research at Cedars of Lebanon Hospital.



12. CARDIOTACHOMETER

Tech Brief

B67-10598     Cardiotachometer with Linear Beat-to-Beat  
Frequency Response

Source:        J.M. Pope, G.J. Deboo and D.B.D. Smith  
                 at Ames Research Center

Technical Support Package is available

Reference:

Pope, J.M., G.J. Deboo, and D.B.D. Smith, "A Cardio-  
tachometer With Linear Indication of Beat-to-Beat Fre-  
quency", Psychophysiology, Vol. 4, No. 4, April 1968.

Transfer:

- 1     Mr. Stan Hutcheson, Memorial Hospital, University  
         of North Carolina, wished to design a cardiotachometer  
         for use on experimental animals exhibiting heart rates  
         in excess of 250 beats per minute. The cardiotachometer  
         will be used to monitor heart rate and changes in heart  
         rate of experimental animals as a result of the adminis-  
         tration of various stimuli and drugs. The R.T.I. team  
         was requested to determine if NASA designed, built and tested  
         circuitry which might be of use in the design of such an  
         instrument. The R.T.I. team identified the cardiac R-wave  
         detector which was originally brought to the attention of  
         the Biomedical Application Team by Tech Brief B68-10144.  
         The completed cardiotachometer will permit obtaining  
         the heart rate of animals for a number of studies involving  
         reaction of test animals to drugs and other stimuli.

Information on Manufacturers

- 1     The Medical Division of the American Optical Corporation,  
         Bedford, Massachusetts is developing an instrument to moni-  
         tor certain functions of bedridden patients. The firm plans  
         to incorporate a cardiotachometer, developed at Ames Re-  
         search Center into their "bedside monitor". Mr. Joseph  
         Panico, Manager, Electronics System, Product Development  
         and Engineering Department, learned about the cardiotacho-  
         meter from the September 1968 issue of Medical Electronics  
         News.

Information on Manufacturers: (cont.)

- 2 An automated system was desired by a researcher investigating the effect of various pharmacological agents upon several parameters of isolated heart cell activity, such as rate of contraction. S.R.I. researchers looked to a linear, low-frequency response cardiometer developed for employment in animal experimentation at the Ames Research Center, for application. Through some reengineering effort, NASA was able to modify the equipment to meet the researcher's needs. The NASA-provided equipment substantially reduced man-hours of observational efforts, increased the accuracy of observations, and significantly expedited progress on the overall research task.

13. CARDIAC R-WAVE DETECTION

Tech Brief:

B68-10144      Cardiac R-Wave Detection

Source:          V. Gebben of Lewis Research Center

Transfers:

- 1 Dr. C.W. Hall of the Baylor University Department of Experimental Surgery, has built a copy of the NASA Cardiac R-Wave Detector, and used it successfully in treating a human patient. The detector will reportedly be made a permanent addition to the DeBakey clinic artificial heart system.

14. CARDIAC CATHETER PRESSURE TRANSDUCER

Tech Brief:

B67-10669     Ultraminiature Manometer-Tipped Cardiac Catheter

Source:       Grant Coon at Ames Research Center

Technical Support Package is available

User Information:

Requests for Technical Support Packages by year:

<u>1967</u>	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>Total</u>
2	117	21	11	151

D.R.I. Questionnaire Results:

Out of 42 questionnaires returned:

2 said TSP "stimulated basic and applied research"

12 said TSP "improved existing process(es) or technique(s)"

2 said TSP "improved existing products and reduced operating costs"

Transfer :

Dr. F. H. Rudenberg, Associate Professor of Physiology at the University of Texas Medical Branch requested information from S. R. I. with regard to an implanted blood pressure transducer for monitoring the blood pressure of rats on a long-term basis. A survey of the literature and existing transducers indicated that instruments suited to Dr. Rudenberg's needs were not commercially available at the time. However, a survey of the technical literature did provide the investigator with information necessary for an assessment of the state-of-the-art. In addition, the SwRI Biomedical Application Team pointed out the applicability of the NASA-Ames transducer, which resulted in the investigator's saving of both time and money. The NASA capacitance transducer developed by Mr. Grant Coon at Ames, while still unavailable commercially, would result in reduction of recovery time and incapacitation as well as substantial improvements in diagnosis and treatments of head injuries.

Information on Manufacturers:

- 1 Smith-Kline Instruments Company  
340 Hillview Avenue  
Palo Alto, California 94304

Smith-Kline Instruments, previously called Corbin-Farnsworth, was contracted by the National Institute of Health to build 50 of Coon's transducers with 50 matching electronic units. Due to manufacturing problems, the contract was revised to include ten transducers and ten electronics units. The National Institute of Health is in the process of testing two of the ten transducers received and five of the electronics units. Smith-Kline will be spending more time on development and hopes for an N. I. H. follow-on.

- 2 Litton Medical Products  
Litton Industries  
1606 Beverly Boulevard  
Los Angeles, California

Litton Medical Products has expressed an interest in manufacturing Ames' ultra-miniature manometer-tipped cardiac catheter, which was invented and patented by Mr. Grant Coon. However, Mr. Coon's invention is already committed to Smith-Kline Instruments.

15. CARDIAC CATHETER PRESSURE TRANSDUCER

Tech Briefs:

B68-10563      Pressure-Sensitive Bonded Junction Transducers

Source:          W. Rindner, A. Iannini, and A. Garfein  
at Electronics Research Center

B69-10690      Miniature Backward-Diode Pressure Sensor  
Features Stability and Low Power Consumption

Source:          W. Rindner and A. Garfein at Electronics  
Research Center

Articles:

Rindner, W. and A. Garfein, "Miniature Tunnel Diode Transducer", Solid-State Electronics, Vol. 10, p.1227, 1967.

Rindner, W. and A. Garfein, "A Miniature Piezo-Junction Pressure Transducer, Proc. IEEE, Vol. 56, p. 1129, 1968.

Rindner, W., A. Garfein, E. Pittelli, and A. Iannini,  
"A Miniature Electromechanical Tunnel Diode Transducer",  
NASA Technical Note D-5451, November 1969.

Information on Manufacturer :

Device Research Inc.  
23 Republic Road  
North Billerica, Mass.

Dr. Wilhelm Rindner, formerly of the NASA Electronics Research Center, is responsible for inventing the cardiac catheter pressure transducer. Dr. Rindner and two of his associates have formed Device Research, Inc., to develop, manufacture, and market solid state transducers and sensors. Dr. Rindner's transducer will be available commercially in 1971, at a competitive price of approximately \$500 - \$950 depending on size and type.

16. AUTOMATIC SPHYGMOMANOMETER

Developed under contract to AiResearch Manufacturing Co.

No Tech Brief is available

"Blood Pressure Measuring System 54803, Project Gemini",  
by J.S. Gould, AiResearch Manufacturing Co., Contract  
#NA59-2887, NASA accession #N65-29782, 7 April 1965.

17. DIRECT FORCE BALANCE PROBE

Tech Brief:

B65-10325      Direct Force -Measuring Transducer Used  
in Blood Pressure Measurement

Source:          G. L. Pressman, P. M. Newgard, and J. J.  
Eige of Stanford Research Institute  
under contract to Ames Research Center

Articles:

- 1 Pressman, G. L. and P. M. Newgard, "A Transducer for the Measurement of Arterial Blood Pressure", NASA CR-53415, 1961.

- 2 Pressman, G. L. and P. M. Newgard, "Development of a Blood Pressure Transducer", NASA CR-53362, 1962.
- 3 Pressman, G. L. and P. M. Newgard, "Development of a Blood Pressure Transducer for the Temporal Artery, " Final Report, NASA Contract NA52-1332, 1964.

18. EAR PULSE PRESSURE TRANSDUCER

Developed under contract by Corbin-Farnsworth, Inc.

No Tech Brief is available.

Articles:

- 1 Corbin, T., Study Program for the Development of a Blood Pressure Measuring and Monitoring System for Remote Use on Man in Flight, Final Report, NASA Contract NASR-35, NR2-10687, 1962.
- 2 Wood, E. H. et al, Measurement of the Blood Content and Arterial Blood Pressure in the Human Ear, Proceedings of the Staff of the Mayo Clinic, July 5, 1950, pp. 398-405.

19. VENOUS PRESSURE MEASUREMENT USING NON-TRAUMATIC TECHNIQUES

Under investigation by S. A. Rositano at Ames Research Center.

20. DIRECTIONAL DOPPLER BLOOD FLOWMETER

No Tech Brief is available

Developed under NASA Grant NRG-33-010-074 by F. D. McLeod, Department of Physiology, Cornell University

Articles:

- 1 McLeod, F. D., "A Directional Doppler Flowmeter", Digest of 7th International Conference on Medical and Biological Engineering, Stockholm, p. 213, 1967.
- 2 McLeod, F. D., "Directional Doppler Blood Flowmeter" Progress Report to NASA, Accession No. N69-31632, May 1969.

- 3 Strandness, D.E., J.W. Kennedy, T.P. Judge, and F.D. McLeod, "Transcutaneous Directional Flow Detection: A Preliminary Report", American Heart Journal, Vol. 78, No. 1, pp. 65-74, July 1969.

Transfers:

- 1 Dr. Bernard Segal at the Medical College of Pennsylvania is interested in developing a transcutaneous technique for early detection of circulatory diseases. He has used one of McLeod's directional doppler blood flowmeters and finds it extremely valuable. According to Segal, who has tested several other blood flowmeters, McLeod has led the field in developing a clinically useable directional doppler blood flowmeter.
- 2 Dr. Strandness (at the School of Medicine, University of Washington and the Veterans' Administration Hospital, Seattle, Washington) is testing McLeod's directional flowmeter and has found it very valuable. He felt that McLeod had the primary responsibility for the development of a useful instrument. Strandness has used the flowmeter to routinely check for several different peripheral vascular diseases and defects.

Information on Manufacturer:

L.M. Electronics  
Daly City, California

As a result of NASA's requirements for the construction of blood flowmeters, they arranged to have L.M. Electronics build several. Consequently, due to their increased expertise, the firm has now sold 30-40 units to private researchers.

21. PULSED DOPPLER BLOOD FLOWMETER

No Tech Brief is available

Developed in part under NASA Grant NRG-33-010-074 by F.D. MacLeod, Department of Aeronautics and Astronautics, Stanford University.

Paper:

Miller, C.W., F.D. McLeod, T.R. Reagan, D.E. Hokanson, and D.E. Strandness, Transcutaneous Measurement of Velocity Distributions in Peripheral Arteries of Man - A Preliminary Report, Center for Bioengineering and Department of Surgery, University of Washington, Seattle, Washington.

Transfer:

Dr. Segal (see ref. 20) is also now using one of McLeod's pulsed Doppler blood flowmeters. Segal felt that McLeod was the first in this country to develop a clinically useable pulsed doppler flowmeter. He has found it extremely valuable in diagnosing peripheral vascular diseases. Although he is trying to calibrate the instrument, his primary goals are to use it to examine the velocity profile in the arteries and veins. He feels confident that the instrument will be a big innovation in the screening and diagnosis of cardiovascular diseases.

22. EAR OXIMETER

No Tech Brief is available

Developed under contract to Ames Research Center by Beckman Instruments, Inc.

Report:

Pintar, Robert R., "Wearable, Wireless Oximeter", Final Report, Contract No. NAS2-1362, Accession no. N65-30480, December 16, 1964.

23. ERGOMETER AND CALIBRATOR

Developed at the Marshall Space Flight Center by R. L. Gause and B. G. Bynum.

24. LOWER BODY NEGATIVE PRESSURE DEVICE

Developed at the Marshall Space Flight Center.

25. MINIATURIZED DOUBLE FOCUSING MASS SPECTROMETER

No Tech Brief is available

Developed for NASA Flight Research Center by Consolidated Systems Corporation, Pomona, California.



Articles:

- 1 Brigden, W.H. and J. Roman, "Flight Research Program: IV. A Small Gas Analyzer for Aerospace", Aerospace Medicine, Vol. 37, No. 10, October 1966.
- 2 Roman, J. and W.H. Brigden, "Flight Research Program: V. Mass Spectrometer in Medical Monitoring", Aerospace Medicine, Vol. 37, No. 12, December 1966.

26. OXYGEN CONSUMPTION RATE COMPUTING SYSTEM

No Tech Brief is available

Developed for MSC under contract by Kubicek et.al., University of Minnesota

Report:

Kubicek, W.G., D.A. Witsoe, R.P. Patterson, M.A. Mosharrafa, J.N. Karnegis, and A.H.L. From, "Development of an Oxygen Consumption Rate Computing System Utilizing a Quadrupole Mass Spectrometer", Contract No. NAS9-4500, Accession #N68-32973, July 1967.

Transfer:

An M. R. I. BATeam reports that apparatus presently being used to compute oxygen consumption rate is too slow to permit breath-to-breath analysis. The team learned that a fast response gas analysis apparatus is being developed for NASA at the University of Minnesota, which will be able to measure oxygen and carbon dioxide on a breath-to-breath basis. The application of this system to the problem was discussed at a meeting of representatives of the University of Minnesota, the University of Kansas Medical Center, and the M. R. I. BATeam. Dr. R. M. Lauer expects to evaluate the oxygen consumption rate computing system, after it is completed.

27. MINIATURIZED MASS SPECTROMETER

No Tech Brief is available

Developed under MSC contract no. NAS9-8371 by Earth Sciences  
(a Teledyne Company)

Report:

Brubaker, W.M., "Astronaut Breath Analyzer", Final Report, Earth Sciences, July 1969.

28. PHOTOIONIZATION MASS SPECTROMETER

Tech Brief:

B70-10402 Improved Photoionization Mass Spectrometer

Source: W.P. Peshchenrieder, J.A.R. Samson, and P.  
Warnek of GCA Corp. under contract to Langley  
Research Center

Document:

Improvement and Optimization of a Mass Spectrometer  
Employing a Photoionization Source, NASA-CR-1018,  
Accession No. N68-17329.

29. M I R A C L E II SYSTEM

Tech Brief:

B70-10528 Technique for Analyzing Human Respiratory  
Process

Source: F.F. Liu of Quantum-Dynamics Inc. under contract to MSC.

30. MODIFIED WRIGHT SPIROMETER

No Tech Brief is available

Developed by James Roman & Robert N. Sato of the Flight  
Research Center.

Document :

Roman, J. and R.N. Sato, A Useful Modification of the Wright Spirometer, NASA Technical Note D-4234, November 1967.

31. TURBINE FLOWMETER

For information contact Dr. John Rummel, Manned Spacecraft Center.

32. PNEUMOTACHOMETER

Tech Brief:

B64-10259      Pneumotachometer Counts Respiration Rate of Human Subject

Source:          Olin Graham of Manned Spacecraft Center

33. PNEUMOTACHOMETER

Tech Brief:

B68-10188      High and Low Pressure Pneumotachometer Measure Respiration Rates Accurately in Adverse Environments

Source:          R. T. McDonald and R. J. Fagot of Northrop Nortronics and J. A. Roman of Flight Research Center.

Document:

McDonald, R. T. and J. A. Roman, Development of Respiration - Rate Transducers for Aircraft Environments, NASA Technical Note D-4217, October 1967.

34. NOSEPIECE RESPIRATION MONITOR

Tech Brief:

B68-10438      Nosepiece Respiration Monitor

Source:          L. E. Long, N. E. Rice, and A. L. Lavery at Electronics Research Center

Transfers:

- 1 Dr. Roy D. Wilson of the Shriners Burn Institute of the University of Texas Medical Branch, posed the problem of assessing the rate and depth of respiration of burned children without touching their bodies, to the SwRI. Dr. Wilson finds present methods unsuccessful because they produce both pain and infection from touching, thus increasing airway resistance and respiratory effort. A nosepiece respiration monitor developed at NASA Electronics Research Center shows evidence of being applicable to this problem, and will be presented to Dr. Wilson for evaluation. Through consultation with the NASA Electronics Research Center, Dr. Wilson will have saved valuable hours which may have been spent in duplicating NASA research. Dr. Wilson may obtain a system which is more accurate and reliable because it represents more research, development time, and money than he could have afforded alone.
- 2 Two medical instrument designers from the Midwestern Corporation are using a NASA Electronics Research Center TSP as a basis for developing an inexpensive nosepiece monitor for use in the diagnosis of eye, ear, nose and throat diseases. The monitor will be inexpensive enough for use in a doctor's office, and will provide the user with data on the rate and amplitude of a patient's respiration.

Interested Companies:

- 1 Technology Transfer Associates, Inc.  
4 West Fourth Avenue  
San Mateo, California 94402
- 2 Advanced Research Corporation  
5100 Wisconsin Avenue, NW  
Washington, D. C. 20016
- 3 Medical Rental and Specialities, Inc.  
45 Elm Street  
West Springfield, Mass.
- 4 Technical Resources, Inc.  
600 Main Street  
Waltham, Mass. 02154
- 5 Geigy Pharmaceuticals  
Ardsley, New York 10502
- 6 Wilton Corporation  
Schiller Park, Illinois 60176

### 35. AUTOMATIC RESPIRATION FAILURE DETECTOR

### Tech Brief:

B68-10365     Automatic Patient Respiration Failure Detection  
System with Wireless Transmission

Source: J.M. Pope and J. Dimeff of Ames Research Center

Technical Support Package is available.

Transfers:

- 1 Dr. Clair Stiles of the Rancho Los Amigos Hospital was faced with the problem of finding a highly effective monitoring device for intubated patients. Full details on the NASA-Ames Research Center's Tech Brief entitled, "Automatic Patient Respiration Failure Detection with Wireless Transmission" were furnished to Dr. Stiles, and through consultation with the NASA development group, and the Biomedical Team, it was decided that the respiration monitor developed at the Ames Research Center would be most applicable to the problem. SwRI reports that the respiration monitor is not intended to substitute for human surveillance, but to provide backup to medical personnel. The NASA device is adaptable for both tracheotomy or completely normal breathing monitoring, as well as alarm. Rancho Los Amigos has already taken in-house steps to reproduce the NASA-Ames device.
- 2 The automatic respiration failure detection device is presently being tested by Dr. Abraham at Children's Hospital in Oakland, California. Dr. Abraham requested a device that would be small, would not require connecting wires that might become entangled, and would give an alarm in the event of a respiratory failure.

### Interested Companies:

- 1 Jordan D. Frasier, President  
Dallas Instruments  
120 Kansas Street  
El Segundo, California 90245
- 2 Sidney Daitch  
Precision Glass and Manufacturing Co.  
5518 North Kedzie Avenue  
Chicago, Illinois 60625

3 Carlo H. Krause, Vice President  
Meridian Lab Inc.  
2611 University Avenue  
Madison, Wisconsin 53705

4 George N. Spain  
Beckman Inst., Inc.  
Clinical Instruments Operations  
2500 Harbor Boulevard  
Fullerton, California 92634

36. HELMET MOUNTED ELECTRODES

Tech Brief:

B66-10536 Helmet System Broadcasts Electroencephalogram of Wearer

Source: R.M. Westbrook and J.J. Zuccaro of Ames Research Center

Technical Support Package is available

Paper :

Westbrook, R. M. and J. J. Zuccaro, "EEG Sensing and Transmitting System Contained in a Flight Helmet," Aero-space Medicine, Vol. 40, No. 4, April 1969

Transfers:

- 1 Mr. Jay Dykstra of Wisconsin State University requested a tech transfer for his research into the physiological parameters of wild birds. Mr. Dykstra's research required two subminiature biotelemetry units without connecting wires, as the normal habitat of the Swifts he studies was chimneys. A colleague of Mr. Dykstra informed him of the NASA documents dealing with telemetry systems, whereupon he requested relevant Tech Briefs. Mr. Dykstra commented that he appreciated the information received, and felt that the telemetry systems would most likely prove to be invaluable to his research efforts.
- 2 Dr. Vladimir Ordon, Senior Research Scientist of Douglas Aircraft Corporation, and Dr. Frank Risch of the Veterans Administration Center in Los Angeles, have been

experimenting with NASA helmet mounted electrodes to monitor the EEG's of active epileptics. The researchers have been experimenting with the electrode in order to find a device which will be capable of detecting and predicting epileptic seizures. The tech transfer was requested subsequent to a conversation with a NASA representative from Cambridge, Massachusetts, who informed the researchers of Ames' research in the area of sponge electrodes. Dr. Ordon stated that the benefits from the use of Ames' electrodes were: establishment of a high quality monitoring system for short observations, a greater variety of electrode systems for comparative purposes, and further gains toward perfecting a method for mounting electrodes on subjects.

- 3 Dr. Milton Wisland, Research Director of the Mental Retardation Developmental Training Center of Indiana University, plans to establish a small residential program at the center for observation of mentally retarded children engaged in a variety of activities. Dr. Wisland plans to use the helmet telemetric system described in an Ames Research Center TSP to facilitate the monitoring of physiological anxiety in mentally retarded children. Dr. Wisland also indicated that the Center may include epileptics in their study, whereupon the helmet system would be used to obtain electroencephalograms which would then be studied to determine what factors influence the pattern and frequency of epileptic seizures.
- 4 Investigators at a Southwest Medical School are in the process of perfecting a technique to test the hearing acuity of young children who may become classified as functional retardates due to acute hearing difficulties. The researchers have developed instruments to provide averaged EEG signals during periods of auditory stimulation, which indicate whether a child hears when auditory stimuli are administered. However, children tend to dislodge the electrodes and interrupt screening procedures with the devices presently utilized. A BA Team suggested the use of an EEG helmet system developed at Ames Research Center to alleviate the dislodgement problem. In addition, a preamplifier noise problem was encountered by the researchers, which was solved through the design of a miniature preamplifier for biological applications. In their subsequent experiments with children, the investigators were pleased with the information received on the EEG helmet system and the performance of the preamplifier.

37. EEG CAP

No Tech Brief is available

Developed by R. M. Westbrook at Ames Research Center

Transfer:

Dr. Westbrook at NASA - Ames Research Center, and Dr. Rappaport of Agnews State Hospital, San Jose, California, are collaborating on a brain sensor and radio transmitter system for diagnosis and treatment of schizophrenic mental patients. The new method is under test at Agnews State Hospital, with fine preliminary results. The sensor-radio system employs only a headset with a tiny battery powered radio transmitter, which is sufficiently lightweight so as not to frighten or alarm the patients; in addition, the absence of wires prevents undue anxiety about anticipated shock therapy.

38. ELECTRONIC SLEEP ANALYZER

Tech Brief:

B70-10110      Electronic Sleep Analyzer

Technical Support Package is available.

39. AUTOMATIC ANALYSIS OF BODY FLUIDS

Tech Brief:

B67-10515      Apparatus Enables Automatic Microanalysis  
of Body Fluids

Source:      J. L. Stuart and G. A. Soffen of the Jet Pro-  
pulsion Lab

Technical Support Package is available.



40. AUTOMATED MICROSYRINGE

Tech. Brief:

B67-10203 Automated Microsyringe is Highly Accurate  
and Reliable

Source: J. L. Stuart and G. A. Soffen of the Jet Pro-  
pulsion Lab

Technical Support Package is available.

This device is used in conjunction with the automatic analyzer.  
The microsyringe is capable of metering extremely small  
volumes of fluid.

41. COLORIMETRIC DETERMINATION OF CREATINE AND CREATININE

Tech Brief:

B67-10245 Automated Urinalysis Technique Deter-  
mines Concentration of Creatine and Crea-  
tinine by Colorimetry

Source: J. H. Rho at Jet Propulsion Lab

42. BACTERIA DETECTION

No Tech Brief is available

The apparatus was developed at Goddard Space Flight Center.  
The following patents have been filed by NASA employees:

- 1 Bacterial Adenosine Triphosphate as a Measure of  
Urinary Tract Infection by E. W. Chappelle and Grace  
L. Picciolo
- 2 Automatic Instrument for Chemical Processing to  
Detect Microorganisms in the Biological Samples  
by Measuring Light Reactions by B. N. Kelbaugh,  
G. L. Picciola, E. W. Chappelle, and M. E. Colburn

43. OCULOMETER

Tech Brief:

B69-10444      Oculometer for Remote Tracking of Eye Movement

Source:          J. Merchant and K.A. Mason of Honeywell Inc. under contract to Electronics Research Center

Information on Manufacturer:

Honeywell Radiation Center  
2 Forbes Road  
Lexington, Mass. 02673

44. OPTOMETER

No Tech Brief is available

The Optometer was developed for the Ames Research Center by Stanford Research Institute. NASA monitor - R.J. Randle

Paper:

Cornsweet, T.N. and H.D. Crane, "Servo-Controlled Infrared Optometer," Journal of the Optical Society of America, Vol. 60, No. 4, April 1970.

Transfer:

For the Ames Research Center, SwRI designed an optometer which determines the speed of visual accommodation -- especially helpful in the visual screening procedures of schoolchildren. The optometer has important clinical implications as it is the first objective measure of a subject's speed and ability to focus, allowing further study into the method of teaching people to focus more effectively. American Optical Company expressed an interest in the optometer and will be a prime manufacturer within a period of two years.

45. AUTOMATED VISUAL SENSITIVITY TESTOR

Tech Brief in review

NASA Technical Note in review

Developed by S.A. Rositano and J.W. Fitzgerald

46. ULTRASONIC BONE DENSITOMETER

No Tech Brief is available

Developed by J.M. Hoop of the Marshall Space Flight Center.

Presently being tested at Campbell Clinic, Memphis, Tennessee.

47. RADIATION PROBE

Tech Brief:

B66-10252     Semiconductor Forms Radiation Probe

Source:        F.P. Burns, J.E. Fredericks of Solid State  
Radiation Incorporated under contract to  
Manned Spacecraft Center

Transfers:

- 1 RTI reports a successful tech transfer to Dr. D.D. Blake and Mr. F.C. Watts, of the Bowman Gray School of Medicine, Wake Forest University, who requested a radiation sensor which could be inserted directly into living tissue or cavities of the human body. Methods available at the time did not accurately measure tissue dose; rather, what was being determined was exposure to radiation. Through a variety of contacts initiated by the Biomedical Applications Team of RTI, the researchers made arrangements to obtain a sample probe for the Bowman Gray School. This tech transfer will allow researchers to accumulate data on actual dosage to specific portions of the human body which they have been unable to obtain by other means.
- 2 A Biomedical Applications Team at SwRI successfully performed a tech transfer to Dr. Hans Wendenburgh of the University of Texas Medical Branch in Galveston, Texas. Dr. Wendenburgh expressed a need for a biocompatible catheter probe to detect concentrations of weak beta radiation from an isotope administered to head-injured patients as a means of monitoring cerebral blood flow. Present monitoring methods are both discomforting to the patient and potentially quite dangerous. Solid State Radiation,

Inc., under contract with NASA, developed a semiconductor radiation detector in the form of a slender probe which is easily inserted into the body tissue. The advantages of using this device mounted on the tip of a catheter are twofold: data can be observed at the input and output points, and the device allows a larger number of data points to be obtained due to the measurement method.

48. INTRAGASTRIC MONITORING SYSTEM

No Tech Brief is available

Paper:

Wise, L., P.W. Jones, G.J. Womack, and W.F. Ballinger, "A Long Term Remote Intra gastric PH, Temperature, Motility and Electrical Activity Monitoring System," 1970, International Telemetering Conference, Los Angeles, California, October 13-15, 1970.

49. AUTOMATED PATIENT MONITOR

Tech Brief:

B68-10131 Automated Patient Monitoring System

Source: R.E. Bedard, W.S. Dawson, and R.L. Buxton  
of the Boeing Company under contract to  
Marshall Space Flight Center

Document:

Bedard, R.E. and R.L. Buxton, Automated Patient Care System, Final Technical Report, Contract N. NAS8-20793, Accession No. N69-23650, January 2, 1968

User Information:

Requested Information:

- 1 Thomas G. Devine, Director  
Patents and Licensing  
Control Data Corp.  
Corporate Headquarters  
8100 34th Avenue South  
Minneapolis, Minnesota 55440

- 2 G. Edward Bilger  
Monsanto Company  
P. O. Box 1531  
Springfield, Mass. 01101
  - 3 Richard Wagner  
Advance Design  
Tally Corporation  
1310 Mercer Street  
Seattle, Washington 98109
  - 4 Mr. Paul Steigman, General Manager  
Altec Lansing  
Intercommunications Division  
A Division of LTV Ling Altec Inc.  
85 Channel Drive  
Port Washington, N. Y. 11050
  - 5 Joseph J. Panico, Manager  
Electronic Systems  
Product Development and Engineering Department  
Medical Division  
American Optical Corporation  
P. O. Box 361  
Crosby Drive  
Bedford, Mass. 01730
- David M. Piatt, Assistant General Manager  
Dallas Instruments  
120 Kansas Street  
El Segundo, California 90245

Transfers:

- 1 Scientists at the Miami Heart Institute have been experimenting with the automated patient monitor and telemetry system in order to monitor individuals with known heart irregularities without disrupting their daily activities. The study hopes to identify factors preceeding cardiovascular emergencies, and to assure that the patient receives aid in the shortest possible time. A request has recently been received asking that the monitoring system be made available for testing in a large multi-phasic patient screening system under development by the U. S. Public Health Service.
- 2 Scientists and Engineers of the Test Instruments Division of Honeywell, Inc., reviewed two NASA Technical Support Packages in order to evaluate their competitive position on the commercial market, one of which was concerned with

automated patient monitoring systems. Honeywell staff members found the TSP's to be clever, simple and efficient; providing a new approach to lightweight monitoring equipment easily adaptable to ambulatory or bedridden patients. Following the review, Honeywell decided to maintain their monitoring system without modification. However, it is possible that Honeywell will utilize any number of segments of the TSP's, as both are being analyzed for future use.

Information on Manufacturer:

Care Electronics Corp.  
3322 Memorial Parkway, S.W.  
Huntsville, Alabama 35805

50. SELF TESTING AND REPAIRING COMPUTER

Tech Brief:

B70-10452 Self Testing and Repairing Computer: A Concept

Source: A.A. Avizienis of Caltech/JPL under contract  
to the NASA Pasadena Office

Technical Support Package is available

Papers:

- 1 Avizienis, A., An Experimental Self-Repairing Computer, Technical Report 32-1356, Jet Propulsion Laboratory.
- 2 Avizienis, A., F.P. Mathur, D.A. Rennels and J.A. Rohr, Automatic Maintenance of Aerospace Computers and Spacecraft Information and Control Systems, AIAA Aerospace Computer Systems Conference, Paper No. 69-966, Sept. 8-10, 1969, Los Angeles.
- 3 Mathur, F.P., and A. Avizienis, Reliability Analysis and Architecture of a Hybrid-Redundant Digital System: Generalized Triple Modular Redundancy with Self-Repair, AFIPS - Conference Proceedings, Vol. 36, 1970.

51.

BIOTELEMETRY

There are six separate items in this section, five of which are related to tech briefs; the sixth section being too new to be documented. Each of the six will be handled separately in order by year, beginning with the oldest.

A.

Tech Brief:

B64-10171      Subminiature Biotelemetry Unit Permits Remote Physiological Investigations

Source:          Ames Research Center

Technical Support Package is available

User Information:Requests for Technical Support Packages by Year:

<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>Total</u>
21	190	40	19	20	290

D. R. I. Questionnaire Results:

Out of 131 questionnaires returned:

5 said TSP "stimulated basic and applied research"

1 said TSP helped "develop new process(es) or technique(s) and new products"

34 said TSP "improved existing process(es) or technique(s)"

27 said TSP "improved existing products and reduced operating costs"

TRANSFERS:

- 1 A medical research team at the Edgewood Arsenal Research Laboratory, Basic Toxicology Branch of the Department of the Army was concerned with the problem of measuring biopotential responses in animals while doing research in basic toxicology. Interest in the Ames-developed subminiature biotelemetry system was stimulated when members of the research team read an article in Medical Electronic News. The relevant Tech Brief and TSP were requested, and several of the biotelemetry systems have been developed as a result of the transfer. Researchers stated that savings in both time and money were afforded by the transfer.

- 2 Mr. A. Frederick Fath of the Information Science Laboratory of the Boeing Scientific Research Laboratories has reportedly been involved in the adaptation of a subminiature biotelemetry unit developed at Ames Research Center, for the purpose of monitoring intensive care cardiac patients past the bedridden stage, for EKG readings. It was determined that the NASA subminiature biotelemetry transmitter was the appropriate device for the monitoring task due to its size, adaptability and cost. Other commercially available transmitters have proven unsatisfactory due to their bulk and poor reliability. Mr. Fath stated that utilization of the NASA device saved him considerable development time and money.
- 3 A research team from the University of Stanford School of Medicine, recently requested information on biotelemetry systems which would permit remote physiological investigations of subjects being studied in survival tests conducted in the Arctic. John C. Klopping, a research assistant at the School, visited the Ames Research Center in search of information on relevant biotelemetry systems. After reading the appropriate Tech Brief, Mr. Klopping realized the applicability of the telemetry unit to the task at hand. The system was successfully used to monitor ECG readings from subjects walking through snow from 35 to 50 feet away. Mr. Klopping stated that if the relevant information had not been available from Ames, Stanford would have had to develop a monitoring system of their own, which would have been infeasible due to their three month time limit for preparation. NASA information resulted in considerable savings to the research team in both time and money.
- 4 A research program at the Institute for Behavioral Genetics of the University of Colorado, under a grant from the National Institute of Health, was concerned with assessing the correlation between EEG, EKG, and EMG readings in mice engaged in sexual activity. The project analyzed patterns of learning and activity in mice, in hopes of increasing their knowledge of man's activities and thought processes within the context of his living environment. Mr. John Stechman, Chief Instrument maker for the Institute, inquired into Ames' research efforts in biotelemetry. The appropriate Tech Brief and TSP were forwarded, and construction of the subminiature transmitter was undertaken. Mr. Stechman estimated that between 100 and 200 manhours would be saved as a result of the tech transfer.
- 5 M. R. I. reports a successful tech transfer to researchers at the Missouri Regional Medical Program of the University of Missouri, who were interested in biotelemetry equipment for a wide variety of uses. Mr. Blair B. Rowley, Research Associate in the Medical Program requested information from the NASA-Ames Center, and action was subsequently taken by an M. R. I. BA Team. The completed biotelemetry unit is now in use in the Missouri Regional Medical Program.



- 6 Dr. David Crowell of the Newborn Psychological Research Laboratory, University of Hawaii, has utilized information received from the Ames Research Center as background data for development of the Laboratory's monitoring systems. The information provided on subminiature biotelemetry systems was reportedly most helpful in avoiding wasted time and effort in system development and application to their study of infant growth, development and reactivity.

Information on Manufacturer:

The Sales Manager of Scientific Advances, Inc., reports that a few prototype units of a telemetering system described in a NASA Tech Brief are being manufactured by the company, and are presently available on the commercial market.

51B. BIOTELEMETRY

Tech Brief:

B65-10203     Tiny Biomedical Amplifier Combines High Performance, Low Power Drain

Source:        T. B. Fryer and G. J. Deboo of Ames Research Center

Technical Support Package is available

User Information:

Requests for Technical Support Packages by Year:

<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>Total</u>
15	105	33	10	13	176

D. R. I. Questionnaire Results:

Out of 79 questionnaires returned:

3 said TSP "stimulated basic and applied research"

1 said TSP "developed new process(es) or technique(s)"

28 said TSP "improved existing process(es) or technique(s)"

10 said TSP "improved existing products and reduced operating costs"

### Transfers:

- 1 Anesthesiologists at the Memorial Hospital for Cancer and Allied Diseases in New York City are currently using an Ames-designed biomedical amplifier, which has been modified to be slightly larger than the model described in the TSP. The amplifier is presently being used as a new monitoring technique for electrocardiogram and electromyogram readings. Mr. Michael N. Leeming, a biomedical engineer at the hospital stated that the major benefit derived from the transfer was the technical design -- rather than identical fabrication.
- 2 Dr. David Lilly of the University of Iowa, Department of Speech Pathology and Audiology, learned of the Ames biomedical amplifier through the trade press. After sending for the NASA TSP, Dr. Lilly and his associates built the amplifier, which has been in successful operation ever since. Dr. Lilly stated that he saved both time and money through this transfer; however, more importantly, he found that the technical assistance was invaluable, as his group was not capable of designing an amplifier themselves.
- 3 Dr. Murray Shevick of the Arlington Medical Center in Riverside, California is using biomedical electronic circuits developed by Ames in instrumenting humans to monitor electrocardiograph readings while conducting "masters" tests. Dr. Shevick received information about the telemetry system from Ames, and turned the project over to an engineer for implementation. Dr. Shevick reported an increase in knowledge of the state-of-the-art, as the major benefit of this transfer.
- 4 Medical personnel in the Albany, California School System are currently using a tiny biomedical amplifier developed at Ames, for the monitoring and tape recording of children's heart tones during physical examinations given at the various schools. The amplifier is used to screen those children with abnormal sounding heart tones. A physician for the school system assembled the amplifier for a very low cost, as he was able to utilize many pieces of equipment already owned by the system. Definite savings in time and money were reported.
- 5 The Bureau of Research in Neurology and Psychiatry at the New Jersey Neuro-Psychiatric Institute has utilized Ames circuitry dealing with the tiny biomedical amplifier. Tube pre-amplifiers were replaced in a Grass Model III EEG in order to eliminate tube noise and to increase accuracy. In addition, the Ames-developed materials will allow the Bureau to stop buying special tubes, which previously cost them a substantial amount of money. Researchers at the Bureau felt that the time and money spent in modifying their Grass Model III EEG was well worth the long term benefits they expect to accrue.

- 6 The University of Tennessee, Department of Medicine has further explored and expanded the Ames-developed miniaturized circuits for the measurement and telemetry of ECG's on animal and human subjects. Researchers in the Department were motivated by the information they received about work done at Ames, to develop a transmitter suited to their particular needs. With additional input from work done on circuit miniaturization at Syracuse University, the researchers proceeded to fabricate miniaturized ECG measuring transmitters, now employed in their research efforts.
- 7 An Electronics Instructor at the School of Technical Vocation, Grossmont College, California, reports the use of NASA information on miniature biomedical instruments, as text material for his course in Biomedical Instrumentation. The instructor finds that NASA material has greatly facilitated the students' understanding of design, engineering, and packaging of subminiature biomedical instruments. Further plans have been made to include NASA information in the biomedical instrumentation curriculum.
- 8 Researchers at the Laboratory of Sensory Science at the University of Hawaii borrowed a tiny biomedical amplifier from Ames Research Center, subsequent to reading an article published in Medical Electronics News. The amplifier was tested and approved for use in measuring the lower potential in sensitive plants (such as the Mimosa), and in measuring nerve potential in the shark with reference to lateral receptivity. To date, actual transfer has not taken place; however, the investigators anticipate substantial savings in time and money.
- 9 Investigators at the University of Wisconsin Laboratory of Neurophysiology, are currently reviewing an Ames-developed tiny biomedical amplifier, in hopes of utilizing it in their research on the monitoring of physiological readings from unrestrained animals in their normal habitat. The researchers hope to obtain a high impedance differential amplifier in miniature form. Information received on NASA innovations and miniature packaging techniques was reportedly very useful to the investigators.
- 10 Dr. Paul-Naitoh of the U. S. Navy Medical Neuropsychiatric Research Unit at San Diego, California, is using information received from NASA on a tiny biomedical amplifier to study the effects of sleep deprivation on experimental subjects. Dr. Naitoh was advised by personnel at the Ames Research Center that the particular amplifier needed in his study was available from D & H Associates, Sunnyvale, California. According to Dr. Naitoh, the NASA information and the availability of the amplifier on the commercial market, could save the Research Unit approximately three months of development time and the equivalent of three man months of effort.

- 11 The Department of Physiology and Anatomy of the University of California at Berkeley is involved in research on the effects of weightlessness and other environmental changes on the cardiovascular system, the urinary metabolism, body temperature, pressures, and other variables. To these ends, researchers at Berkeley consulted NASA briefs and relevant TSP's for information on appropriate miniature implantable transmitters and measuring devices, as well as external measuring devices for use with humans. Designs from the Ames Research Center were either partially or wholly applicable to the investigators' circuitry needs. It was reported that several man-weeks of technical effort were saved as a result of this transfer.
- 12 The Department of Radiobiology of the University of California at Davis was conducting an evaluation of their in-house telemetry systems, when an article appeared in Electronic Design with respect to telemetry systems developed at the Ames Research Center. Two of the Ames systems were purchased as a result of this article, in order to compare the reliability and stability of the Ames systems with those developed at the University. Two additional telemetry systems manufactured by the Electro-Optical systems of Whittaker Corporation, also based on Ames Research, will be compared with the instruments designed at the University in the near future.
- 13 Dr. David Crowell of the Newborn Psychological Research Laboratory, University of Hawaii, has utilized information received from the Ames Research Center as background data for development of the Laboratory's monitoring systems. The information provided on tiny biomedical amplifiers was reportedly most helpful in avoiding wasted time and effort in system development and application to their study of infant growth, development and reactivity.

#### Information on Manufacturers:

- 1 Dallons Laboratories  
120 Kansas Street  
El Segundo, California

Dallons Laboratories, a subsidiary of International Rectifier Corporation, manufactures medical electronics equipment for sale to hospitals and medical personnel. Engineers were concerned that the transmitter being produced by the company was too heavy and bulky and resulted in high power drain. Their goal was to produce a new implantable transmitter with a smaller power drain, which was lighter and more compact as well. Before actually designing the proposed transmitter, Dallons requested NASA information on the tiny biomedical amplifier, which proved to offer the

ideal circuitry for their needs. The Chief Engineer at Dallons was unable to estimate their savings as a result of this transfer, but feels that the information received was quite valuable to the company.

- 2 D & H Associates  
Sunnyvale, California

#### 51C. BIOTELEMETRY

##### Tech Brief:

B66-10057      Miniature Bioelectronic Device Accurately  
Measures and Telemeters Temperature

Source:          T.B. Fryer of Ames Research Center

Technical Support Package is available.

##### User Information:

##### Requests for Technical Support Packages by Year:

1966	1967	1968	1969	1970	Total
31	119	94	21	17	282

##### D. R. I. Questionnaire Results:

Out of 96 questionnaires returned:

2 said TSP "stimulated basic and applied research"

1 said TSP "developed new process(es) or technique(s)"

28 said TSP "improved existing process(es or technique(s))"

23 said TSP "improved existing products and reduced operating costs"

##### Transfers:

- 1 Dr. N. R. Scott of the Department of Agricultural Engineering of the New York State College of Agriculture, has built a miniature temperature telemetering device based on information received from the Ames Research Center. Dr. Scott intends to implant the transmitter in a chicken to study the effects of environmental change in temperature, humidity, air movement and radiant temperature, on the chicken's temperature. Dr. Scott feels that the NASA design for temperature telemetry actually gave impetus to the project. If his re-

sults with the first transmitter are successful, Dr. Scott intends to build four additional transmitters for use in his projects.

- 2 Dr. R. L. Dreyer of the University of Iowa College of Medicine obtained information and an associated TSP, of a miniature sensing and transmitting device developed at the Ames Research Center. Dr. Dreyer is presently evaluating and experimenting with a miniature bio-telemetry instrument for use in a study of heat production in the adipose tissue of hibernating bats. The Ames instrument has been modified to reduce its weight, due to the diminutive size of the subject. It was estimated by Dr. Dreyer that the Technical Support Package may account for as much as 75% of the useful information related to the development of his telemetric instrument.
- 3 A research effort at the Johns Hopkins University School of Medicine is concerned with ascertaining the true normal body temperature. Researchers are presently using a bioelectronic device developed at Ames Research Center which accurately measures and telemeters temperature. The research team hopes to publish an article on the system they have designed resulting from their use of NASA materials. It was reported that the investigators saved valuable time and development money by virtue of this transfer.
- 4 Dr. R. J. Meyer of the Department of Zoology, University of Wisconsin is engaged in endocrinology research on monkeys. In response to his request for a suitable instrument to be used to measure and telemeter the temperatures of internal organs and body cavities of monkeys, an M.R.I. BATeam obtained information on the NASA temperature telemetry system, which was subsequently forwarded to Dr. Meyer. One of the telemetry units has been successfully implanted in an ovariectomized monkey since May, 1968 without any tissue reaction. Considerable data has already been accumulated with regard to diurnal temperature changes, and changes resulting from drug reactions.
- 5 Biopotential Systems, Inc., of Pennsylvania is a small company involved in the medical electronics business. The company has been granted a license to use the NASA miniature bioelectronic device described in Tech Brief B66-10057. Edward Young, President of the company, reports that the device has been modified to operate without a battery. The company hopes to eventually market this product; however, work on it has been temporarily suspended. Mr. Young indicated that NASA technology has been particularly helpful - especially in initiating the development of the instrument.

51D. BIOTELEMETRY

Tech Brief:

B66-10624     Miniature Telemetry System Accurately Measures Pressure

Source:        T.B. Fryer of Ames Research Center

Technical Support Package is available

User Information:

Requests for Technical Support Packages by Year:

<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>Total</u>
0	79	40	18	19	156

D.R.I. Questionnaire Results:

Out of 59 questionnaires returned:

4 said TSP "stimulated basic and applied research"

15 said TSP "improved existing process(es) or technique(s)"

12 said TSP "improved existing products and reduced operating costs"

Transfers:

- 1 A technician working for Dr. Turbyfill of the Armed Forces Radiobiology Research Institute, informed him of the pressure measuring system developed at NASA-Ames, in hopes that the device would be applicable to their work in biopressure measurement of rhesus monkeys and dogs. Dr. Turbyfill purchased four transducers and transmitters from Bio-Optical, a subsidiary of Whittaker Corporation, which proved to meet the Institute's requirements with only minor modification. The cost of the equipment was \$500; Dr. Turbyfill estimates that the same devices, developed under contract, would have cost as much as \$50,000.
- 2 A miniature diaphragm-type capacitance transducer, developed at NASA's Ames Research Center, has been used successfully on heart patients at the Stanford University Medical Center.
- 3 An endocrinologist at the University of Wisconsin needed an implantable instrument to measure small temperature changes of internal organs and cavities in monkeys, without causing

adverse reactions. A literature search turned up a small temperature telemetry system developed at the Ames Research Center, which would seem to apply to his problem quite well. Purchase of the unit has resulted in satisfactory implantation in a monkey for more than three months.

51E. BIOTELEMETRY

Tech Brief:

B68-10065 Multichannel Implantable Telemetry System

Source: T.B. Fryer of Ames Research Center

Technical Support Package is available

User Information:

Requests for Technical Support Packages by Year:

<u>1966</u>	<u>1967</u>	<u>1968</u>	<u>1969</u>	<u>1970</u>	<u>Total</u>
0	0	143	32	20	145

D.R.I. Questionnaire Results:

Out of 17 questionnaires returned:

1 said TSP "stimulated basic and applied research"

3 said TSP "improved existing process(es) or technique(s)"

3 said TSP "improved existing products and reduced operating costs"

Transfers:

- 1 Lieutenant Commander Jerry A. Phelps, U.S. Naval Hospital, Camp Lejeune, North Carolina, plans to use a telemetry system developed at the Ames Research Center for monitoring the electrocardiograms of patients in the operating room. Commander Phelps first learned of the NASA Technical Support Package through the September 1968 issue of Medical Electronics News. The system as he contemplates it, will not actually be implanted in the patient, but will be attached while the patient remains in the operating room. Final plans will be implemented after Commander Phelps' retirement from the Army.
- 2 Dr. John Boucher, formerly affiliated with the Ohio State University College of Veterinary Medicine, requested information about a multi-channel implantable telemetry



system for use in his work with chronically instrumented dogs. Dr. Boucher's experiment necessitated the measurement of blood flow and blood pressure, the latter procedure requiring a telemeter. Information acquired from Ames materials and a TSP were not applicable to this project per se, but will be used in Dr. Boucher's current military research assignment. The information received from the TSP was still useful to the experiment at Ohio State, and Dr. Boucher estimates that approximately six man months of professional effort were saved as a result of the transfer.

- 3 A research team composed of ten faculty members, four researchers and several graduate research assistants within the Department of Psychology at Baylor University requested information from NASA-Ames with regard to monitoring neurophysiological functioning of experimental subjects. Professor Thompson, a team member and regular reader of NASA publications, noticed the multichannel implantable telemetry system in a Tech Brief, and suggested that the device might be just what the research team was looking for. After surveying the TSP, it was decided that the telemetry system was indeed the best solution, and the team plans to proceed with their project by implanting the system in Rhesus monkeys.
- 4 Scientists and Engineers of the Test Instruments Division of Honeywell, Inc., reviewed a NASA Technical Support Package on multichannel implantable telemetry Systems, for an evaluation of their commercial position. Members of the investigation team found the TSP to be extremely helpful in suggesting an alternative approach to lightweight monitoring equipment for use by ambulatory or bedridden patients. Honeywell decided to maintain their monitoring system without modification; however, the TSP is being analyzed for future expansion and possible manufacture for commercial uses.
- 5 An Assistant Professor of Zoophysiology at the University of Alaska is attempting to apply an Ames developed implantable telemetry system in his study of adaption behaviors of beavers to extreme cold. A comparative analysis of body temperatures and EKG's of beavers during summer and winter months is planned. Professor Miller estimates that this transfer will eventually provide considerable savings in dollars spent and data collection efficiency.
- 6 Dr. Kieffer of the Armed Forces Radiobiology Research Institute has utilized circuits designed by Ames Research Center in order to fabricate telemetry units for implantation in dogs and other animals exposed to radiation. Dr. Kieffer hopes to determine the effects of radiation on various animal body functions. Although the Ames-developed telemetry instruments were not quite resistant enough to

radiation, technical personnel at the Institute are modifying the design to include components which will be more resistant to radiation effects. Dr. Kieffer found the tech transfer cost-effective and quite valuable to his research.

Information on Manufacturers

- 1 Sensotec  
1400 Holly Avenue  
Columbus, Ohio 43212
- 2 Electro-Optical Systems, Inc.  
300 North Halsted Street  
Pasadena, California 91107
- 3 Whittaker Corporation  
Instrument Systems Division  
1120 South Arroyo Parkway  
Pasadena, California 91105

51F. BIOTELEMETRY

No Tech Brief is available.

Miniature Biotelemetry - Phase 1 Plan by John Carraway of  
Jet Propulsion Lab

52. INTEGRATED MEDICAL AND BEHAVIORAL LABORATORY  
MEASUREMENT SYSTEM

For information contact: Dr. Samuel Pool at Manned Space-  
craft Center.

53. MEDICAL INFORMATION COMPUTER SYSTEMS

For information contact: Dr. E. C. Moseley at Manned Space-  
craft Center

## APPENDIX B

### BRIEF HISTORY OF THE USE OF CARDIAC CATHETERS FOR BLOOD PRESSURE MEASUREMENT

- 1905 First known insertion of a catheter into human veins done by Fritz Bleichroeder
- 1929 Forssman inserted catheter into his own right atrium
- 1933 Hamilton, Brewer, and Brotman performed a study of frequency response and sensitivity of catheter systems.
- 1941 Cournand and Ranges established widely accepted procedures for cardiac catheterization
- 1943 Wetterer developed differential transformer transducer for pressure measurement using catheters
- 1947 Lambert and Wood designed a strain gauge transducer for pressure measurement in small peripheral arteries.
- 1947 Statham Instruments, Inc. commercially produced the first Model P23 strain gauge transducer
- 1950 Gauer and Grenapp developed a miniaturized differential transformer for use on the tip of a catheter
- 1951 Verhagen and his coworkers built a catheter tip transducer with a frequency response to 50 Hz
- 1954 Smith used semiconductors in the construction of strain gauges for transducers
- 1955 Bromberg and Barnea designed several miniaturized catheter tip transducers
- 1955 Statham Instruments, Inc. marketed the improved P23Db strain gauge transducer
- 1957 Mason and Thurston used semiconductors to design strain gauges for transducers
- 1957 Noble developed sonic valve pressure gauge for pressure measurement
- 1958 Warnick and Associates designed a strain gauge transducer
- 1959 Gauer and Grenapp advanced the design of their differential transformer transducer
- 1960 Sanchez built a miniaturized semiconductor strain gauge with high sensitivity
- 1960 Traite developed a piezo resistive silicon crystal for use as a transducer

1961	Sanchez, Wright and Moen each designed advanced miniaturized semiconductor strain gauges with high sensitivity
1961	Gauer and Grenapp's differential transformer transducer was improved by Alland, Laurens and associates and commercialized by Telco Medical Electronics Co.
1963	Angelakos and Micro-Systems, Inc. developed a miniature silicon strain gauge transducer
1963	Grant Coon of NASA Ames Research Center developed a welded pressure transducer for wind tunnel testing
1964	Satham Instruments, Inc. marketed the SF1, a miniature strain gauge tip transducer
1966	Grant Coon reduced size of his capacitive pressure transducer to .09 inches in diameter
1966	Coon's transducer was reduced further to .058 inches
1967	Coon built a .043 inch transducer
1967	Coon successfully reduced transducer to .04 inches
1968	Smith, Kline Instruments obtained rights to produce Coon's transducer for NH
1968	Dr. Rindner of NASA's Electronic Research Center designed pressure sensitive bonded junction transducer
1969	Satham Instruments, Inc. marketed the P866 strain gauge tip transducer
1969	Rindner developed a miniature electromechanical tunnel diode transducer for use on the tip of a catheter
1970	Rindner obtained license and formed company to manufacture catheter tip transducers
1970	Smith, Kline Instruments delivered prototype catheter tip transducers to NH (originally designed by Coon)
1971	Projected marketing of Rindner's catheter tip transducer

1961

1962

1963

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1965

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1967

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